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BRANCHIAL CIRCULATION IN *MACROPODUS OPERCULARIS L.*

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The purpose of this paper is to describe the adult vascular system of the branchial region in *Macropodus opercularis*, and to present some developmental details of this system starting with the free swimming larva.

Macropodus opercularis, the forked-tailed paradise fish, is listed by Jordan (1923) under the Order Labyrinthici, Family Osprohomenidae. This species is normally found in lowland streams and ponds of China and Formosa. The ability of the paradise fish to utilize atmospheric oxygen in addition to the normal gill respiration adapts it to life in stagnant waters.

The presence of the labyrinth structure in this fish and related species has led a number of investigators to study the nature of the accessory respiratory apparatus. Zograff (1888) and Day (1868) have shown that the labyrinth structure is used by the fish to retain air and not water as was originally believed. Henninger (1907), Das (1927), and Bader (1937) have shown that the labyrinth fish die when deprived of free access to atmospheric oxygen even if supplied with well oxygenated water. Bader (1937), confirming the work of Henninger (1907), has probably made the most detailed study of the blood system in the adult fish.

The present study dealing with the adult vascular system agrees with the description given by Bader (1937). The developmental details presented in this study add some details not found in the present literature.

MATERIALS AND METHODS

The species utilized in this study was *Macropodus opercularis*. Pairs were bred approximately every 4 weeks in controlled temperature tanks. The optimum temperature for breeding seemed to be between 27–30°C. Fish raised in the same tank from the same group of eggs show considerable variation in rates of growth. A range in size of from 5.0 mm. to 11.2 mm. 4 wk. after hatching represents an extreme example of variability in rates of growth. Subsequent studies of serial sections have shown little developmental difference between fish of the same size but of different age. For this reason, age groups were discarded in favor of measurement of length as a criterion for degree of development.

All fish measurements are based on standard length described by Hubbs (1943) that is, distance from the most anterior part of the head backward to the end of the vertebral column.

All fish were fixed in Bouin's fixative 6 to 24 hr. depending on the size of the fish. Serial paraffin sections were made of the head and body region of the fish. The sections were cut from 8 to 15 μ in thickness. The stains used were Dela-

field's hematoxylin and eosin, and Mallory's Triple Connective Tissue stain. Dioxane was used in place of the graded series of alcohols for dehydration purposes.

Photographic reconstructions (fig. 1) were made of the following stages, 2.9, 3.4, 4.3, 5.1, 7.4, and 11.2 mm.

OBSERVATIONS

A. 2.9, 3.4, and 4.3 mm. Stages

The general course and distribution of the afferent and efferent branchial arteries observed in these 3 stages were found to be similar. The 2.9 mm. fish represents the earliest free-swimming larval stage.

With a few minor exceptions the course and distribution of the afferent and efferent branchial arteries of these early stages are similar to the conditions found in Teleosts. (figs. 9, 10).

The efferent branchial artery IV although quite small was observed in the fourth branchial arch. Its junction with either the third efferent artery or the dorsal aorta was not found. It is possible that this junction does take place through small capillary vessels. The pair of efferent branchial arteries III one on each side, after passing through the branchial arches, were observed to join medially forming the dorsal aorta. Slightly anterior to the junction of the two efferent branchial arteries III, the dorsal aorta branches forming two lateral dorsal aortae. The efferent branchial arteries II and I join the lateral dorsal aortae. Anterior to the junction of the lateral dorsal aortae and the efferent arteries I, the lateral dorsal aortae continue anteriorly and seem to correspond functionally to the internal carotids. Just before its junction with the lateral dorsal aorta the first efferent branchial artery gives off a small branch which proceeds forward along the inner wall of the labyrinth groove, where it breaks up into capillaries.

The afferent branchial arteries observed in all stages of *Macropodus* were found to follow the same pattern commonly observed in Teleosts. The first and second afferent arteries arise independently from the ventral aorta, while the third and fourth pairs arise from the ventral aorta by means of a short common stem.

B. 5.1 mm. Stage

The development of the labyrinth groove which is to form the labyrinth organ of the adult fish is accompanied by some changes in the efferent branchial arteries (fig. 8). As in the earlier stages described, the third and fourth efferent branchial arteries join and empty into the dorsal aorta by means of a common trunk. Anterior to this common trunk the dorsal aorta branches forming the two lateral dorsal aortae. The second efferent branchial arteries from either side join the lateral dorsal aortae. Several changes in the efferent branchial system were observed.

1. The internal sacculus artery arises from the second efferent branchial artery just before it joins the lateral dorsal aorta. The internal sacculus artery continues anteriorly for a short distance before dividing into two branches. One branch continues forward and laterally toward the inner wall of the labyrinth groove where it breaks up into capillaries. The second branch was also observed to form a capillary network along the inner wall of the labyrinth groove.

2. The first efferent branchial artery instead of joining the lateral dorsal aorta continues anteriorly as the labyrinth artery. The labyrinth artery was traced as far as the anterior dorsal side of the labyrinth groove where it eventually breaks up into capillaries.

C. 7.4 and 11.2 mm. Stages

The vascular system of the branchial region observed in these two stages is substantially identical with the description given by Bader (1937). At these later stages the labyrinth organ is completely formed. A description of this organ is given by Bader (1937).

The third and fourth efferent branchial arteries unite to form a common trunk. The right and left common trunks unite forming the dorsal aorta. The common carotid arteries originate on either side from the efferent branchial artery III, just before its union with the efferent branchial artery IV. The common carotids after their origin proceed anteriorly for a distance before each divides into an internal and external carotid artery. The external carotid continues anteriorly along the inner wall of the labyrinth organ. The right and left internal carotids also proceed anteriorly and gradually converge. The two internal carotids pass between the pseudobranchs and unite just anterior to the pseudobranchs forming the circulus cephalicus (fig. 2).

The second efferent branchial artery does not join the dorsal aorta directly or indirectly through a lateral dorsal aorta. The second efferent branchial artery continues anteriorly as the internal sacculus artery along the inner wall of the labyrinth organ. Along its course the internal sacculus continues to subdivide forming a capillary network.

The first efferent branchial artery does not contribute directly or indirectly to the formation of the dorsal aorta. After leaving the gill arch the first efferent artery continues anteriorly along the labyrinth plate as the pabyrinth artery. Along its course the labyrinth artery continues to subdivide forming a network of arterial capillaries. The external sacculus artery originates from the first efferent branchial artery just before the first efferent artery continues anteriorly as the labyrinth artery. The external sacculus artery proceeds anteriorly along the outer wall of the labyrinth organ (fig. 4). This artery also subdivides and eventually forms a large capillary network along the outer wall of the labyrinth organ.

The blood from the head and labyrinth organ is returned to the heart by means of several large vessels. The labyrinth vein drains and collects blood from the inner wall of the labyrinth cavity. The blood from the inner wall of the labyrinth cavity, as well as the blood from the anterior and posterior portion of the cavity is collected by the two internal sacculus veins. (fig. 5.) The jugular vein drains the head region. The labyrinth vein, the external, and the two ininternal sacculus veins all empty into a large collecting sinus called by Bader (1937) the "Venoser sommelraum." (fig. 6) The blood is drained from this sinus into the jugular vein. The two jugular veins proceed posteriorly and empty the blood into the sinus venosus. (fig. 11).

The venous system draining and returning the blood from the head and body regions anterior to the heart is very much simplified in the early stages. From the 2.9 to 5.1 mm. stages, the only large veins observed were the jugular veins. The external and internal sacculus veins and the labyrinth veins found in the adult were not observed in the early stages.

DISCUSSION

The vascular system of the branchial region in the adult *Macropodus* deviates considerably in some respects from the pattern commonly found in Teleosts. It is quite possible that the development of the supplementary respiratory apparatus, the labyrinth organ, found in *Macropodus*, is a contributing cause of these deviations.

With some slight variations, all four efferent branchial arteries in Teleosts empty into the lateral dorsal aorta. In some instances as pointed out by Allis (1912),

all four pairs empty independently into the lateral dorsal aorta, while in other instances, the first two pairs of efferent arteries empty independently into the lateral dorsal aorta and the third and fourth pairs first unite forming a short common stem. The pattern found in *Macropodus* is somewhat different. The first and second efferent arteries do not empty into the dorsal aorta, but proceed anteriorly as the labyrinth and internal sacculus arteries.

In Teleosts, as described by Allis (1912), the external carotid has its origin in the angle formed where the first efferent branchial artery joins the lateral dorsal aorta. After giving off its external carotid, the lateral dorsal aorta becomes the internal carotid. The common carotid is extremely short. In the adult *Macropodus* the common carotid is relatively long and originates from the third efferent branchial artery. The common carotid after its origin from the third efferent artery continues forward for some distance then divides into the external and internal carotids.

The venous system of the branchial region of the adult *Macropodus* also differs from the common Teleost pattern. The labyrinth vein, the external and two internal sacculus veins, and the large collecting sinus make up a relatively large venous system not found in Teleosts (fig. 11).

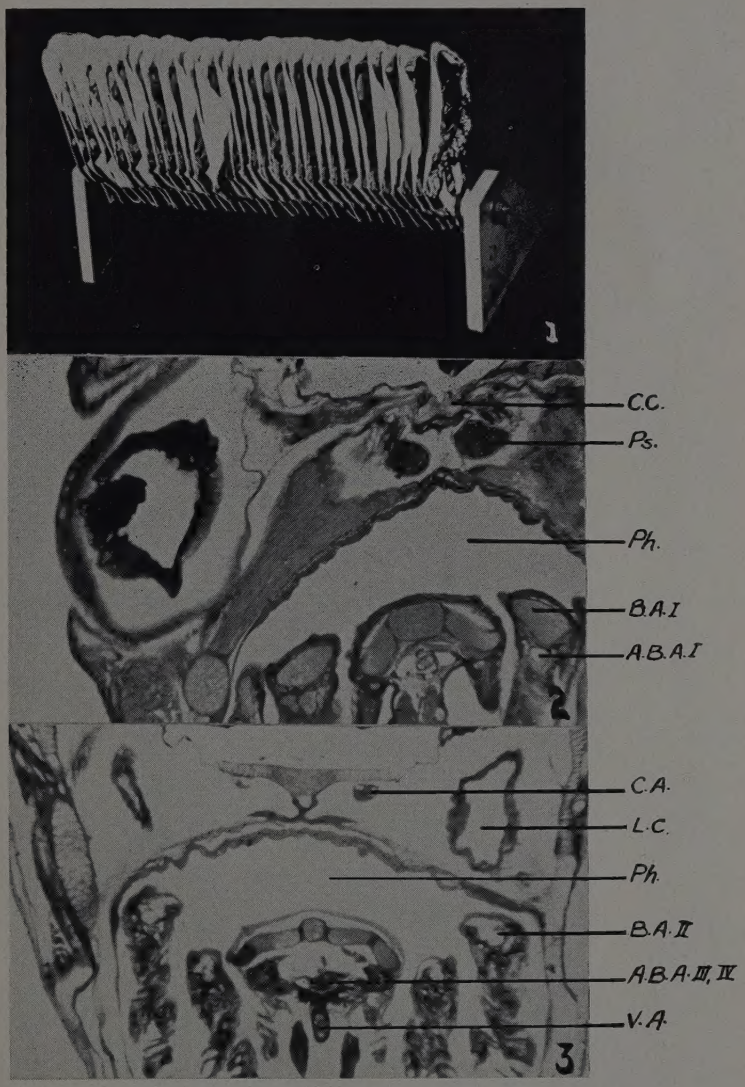
The study made of the various serial sections of *Macropodus* shows a gradual change in the vascular system of the branchial region. In the early stages, the 2.9 to 4.3 mm., the vascular system of the branchial region in *Macropodus* follows the general Teleost pattern. In the 5.1 mm. stage the first efferent branchial artery does not join the lateral dorsal aorta, but proceeds anteriorly as the labyrinth artery. The common carotid artery seems to be a continuation of the lateral dorsal aorta. In the 7.4 mm. stage neither the first nor the second efferent arteries join the dorsal aorta, the second efferent artery proceeding anteriorly as the internal sacculus artery. The common carotid originates from the third efferent branchial artery.

The study of the various serial sections seems to indicate that the changes in the branchial circulation of Macropodus occur gradually as the labyrinth organ develops.

For the sake of comparison, diagrammatic drawings of the branchial circulation are given in figures 7 to 10.

SUMMARY

1. Length rather than age of *Macropodus* is a more accurate criteria for determining the stage of development.
2. The vascular system of the branchial region in the early stages up to the 4.3 mm. stage in *Macropodus* is similar to the common Teleost pattern.
3. In the 5.1 mm. stage the first efferent branchial artery no longer empties into the lateral dorsal aorta but continues anteriorly as the labyrinth artery.
4. In the 7.4 mm. fish neither the first nor the second efferent arteries empty into the dorsal aorta. The second efferent artery continues anteriorly as the internal sacculus artery. The common carotids originate from the third efferent arteries.
5. The adult *Macropodus* possesses a relatively large and unique venous system in the branchial region consisting of the labyrinth vein, the external sacculus vein, and two internal sacculus veins draining blood from the labyrinth organ.
6. Observations show that the deviations from the common Teleost pattern occur as the accessory respiratory apparatus, the labyrinth organ, develops.



1. Photographic reconstruction used to study the circulatory system.
2. Transverse section of an 11.2 mm juvenile fish through the pseudobranchs and through the posterior part of the eye. X93.
3. Transverse section of a 7.4 mm. fish showing the common stem formed by the 3rd and 4th efferent branchial arteries. X 93.

(See page 135 for Abbreviation Key)

4. Transverse section of an 11.2 mm. fish through the labyrinth chambers. X93.
5. Transverse section of an 11.2 mm. fish through the posterior portion of the labyrinth chambers. X93.
6. Transverse section of the same fish showing the venous collecting sinus—"Venoser sammelraum". X93.

(See page 135 for Abbreviation Key)

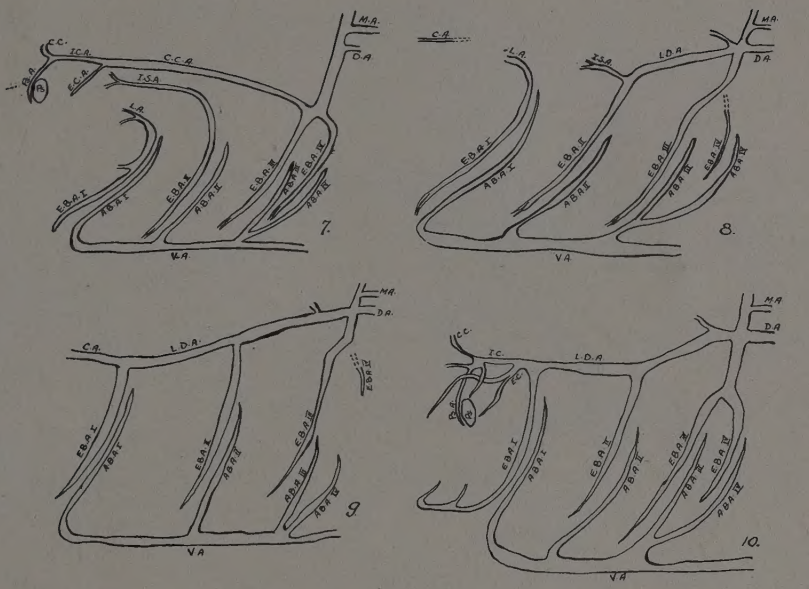


FIGURE 7. Lateral view of the branchial arteries of the adult *Macropodus* shown diagramatically.
FIGURE 8. Similar view of a 5.1 mm. *Macropodus*.
FIGURE 9. Similar view of early stages up to 5.1 mm. in *Macropodus*.
FIGURE 10. Similar view of Teleost system. Adapted from Allis (1912).

ABBREVIATION KEY

A.B.A.	Afferent branchial artery
B.A.	Branchial arch
C.A.	Carotid artery
C.C.	Circulus cephalicus
C.C.A.	Common carotid artery
D.A.	Dorsal aorta
D.C.	Dorsal chamber of labyrinth chamber
E.B.A.	Efferent branchial artery
E.C.A.	External carotid artery
E.S.A.	External sacculus artery
E.S.V.	External sacculus vein
I.C.A.	Internal carotid artery
I.S.A.	Internal sacculus artery
I.S.V.	Internal sacculus vein
J. V.	Jugular vein
L.A.	Labyrinth artery
L. C.	Labyrinth chamber
L.D.A.	Lateral dorsal aorta
L.V.	Labyrinth vein
M.A.	Mesentary artery
Ph.	Pharynx
Ps.	Pseudobranch
Ps.A.	Pseudobranchial artery
V.A.	Ventral aorta
V.C.	Ventral chamber of labyrinth chamber
V.S.	Venoser sammelraum

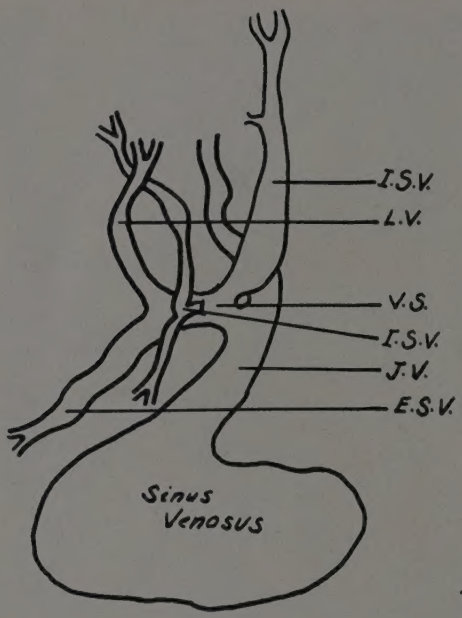


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FIGURE 11. Reconstruction after Bader (1937) showing the veins associated with draining the labyrinth organ.

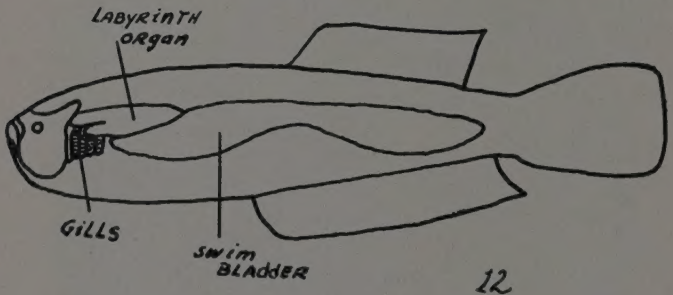

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FIGURE 12. The labyrinth organ in relation to the general morphology of the head and branchial region. Adapted from Bronns (1940).

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ON THE EXISTENCE OF CHRONOLOGICAL VARIATIONS IN THE COMPOSITION OF ROMAN BRASS[1]

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In spite of some literary allusions to the contrary, the experimental evidence indicates that the copper-zinc alloy which we call brass was first produced intentionally by the Romans. This alloy was first used by them only for coins, and there are strong indications that its manufacture was practiced by the Roman mints as a monopoly of the state during most or all of the period when brass was struck. The earliest known Roman brass coins were issued under Julius Caesar about 45 B. C., but the abundant issue of such coins did not begin until about 23 B. C. under Augustus. Vast numbers of these coins were issued under various emperors between this date and 200 A. D., the approximate time of the end of the ancient coinage of this alloy.

In the course of listing and comparing all known chemical analyses of Roman brass coins, including some made recently in his laboratory, the author observed the existence of systematic chronological changes in the composition of the alloy. The nature and extent of these changes are illustrated by the results of a series of careful analyses of closely dated coins shown in table 1. Five of these analyses

TABLE 1

Analyses of closely dated Roman brass coins

Date	Cu %	Ag %	Au %	Sn %	Pb %	Fe %	Ni %	Zn %	Total %
23 B.C.	77.36	none	none	0.17	0.16	0.38	none	21.88	99.95
39–40 A.D.	81.03	none	none	none	0.05	0.22	0.03	18.55	99.88
96–98 " "	84.69	none	none	0.57	0.49	0.38	0.05	13.59	99.77
141 " "	86.28	0.06	trace	0.06	0.32	0.51	0.02	12.71	99.96
154–155 " "	86.51	0.10	trace	1.69	0.11	0.33	0.03	11.14	99.91
161–162 " "	88.96	0.05	trace	2.43	0.18	0.31	0.04	7.87	99.84

were made by Mr. W. H. Deebel as part of a thesis for the M. Sc. degree at The Ohio State University. The remaining one was made by Messrs. A. Randall and N. Lovegren working in the author's laboratory. A more or less regular chronological increase in the proportion of copper and a corresponding decrease in the proportion of zinc is evident throughout this series. Furthermore, the number and total proportion of the various impurities tend to increase with time, though these changes are much less regular than the changes in the proportions of copper and zinc. Shown in table 2 are figures for the average proportion of zinc and the maximum proportion of zinc in coins of a series of four successive emperors. These figures represent all known reliable determinations of the zinc content of brass coins of these emperors. The more or less regular decrease in the proportion of zinc is obvious. In table 3 are shown the average proportions of zinc, tin, and lead in Roman brass coins by half-century periods, as given by all known reliable analyses. Here again the chronological decrease in proportion of zinc is obvious.

[1]Paper presented at the Sixty-third Annual Meeting of the Ohio Academy of Science, Athens, Ohio, April, 1954.

Also obvious is a corresponding more or less regular increase in the average proportions of tin, and lead, with the average proportion of tin always greater at each period than the average proportion of lead. The proportions of these two principle impurities increase to such an extent that their sum in the last period almost equals the proportion of zinc.

This chronological decrease in the proportion of zinc in Roman coinage brass was probably caused by a practice that has been followed almost of necessity by mints in all countries at all periods. This is the use of coins badly worn by circulation as the principal source of metal for the issue of new coins. Often the new

TABLE 2

Zinc content of coins of a series of successive emperors

Emperor and period of reign	Number of determinations	Average zinc content %	Maximum zinc content %
Trajan 98–117 A.D.	10	14.1	16.7
Hadrian 117–138 A.D.	12	12.7	16.8
Antoninus Pius 138–161 A.D.	8	10.5	13.6
Marcus Aurelius 161–180 A.D.	10	6.6	10.3

TABLE 3

Average zinc, tin, and lead content at successive periods

Period A.D.	Number of analyses	Zn %	Sn %	Pb %	Sn+Pb %
1–50	5	21.10	0.10	0.08	0.18
51–100	4	12.45	0.50	0.28	0.78
101–150	20	10.62	1.35	0.72	2.07
151–200	18	6.05	3.54	2.33	5.87

metal that is added corresponds only to the amount of metal lost through circulation. When a nearly pure single metal is used for coins, this practice does not lead to much change in the composition of the coinage metal on remelting, but when an alloy is used a considerable change may occur because of the preferential loss of one component by oxidation. With brass this change in composition tends to be especially large because the zinc is not only more easily oxidized than the copper but is also lost by volatilization. Even if the Roman coiners had added a considerable proportion of new brass on remelting, the resulting coinage brass would generally have contained less zinc than the worn coins, for they were apparently unable to manufacture brass that contained more than about 25 percent zinc. This indicates that all their brass was made by a cementation process, that is by the reduction of zinc ores with carbon in the presence of molten copper. There is no evidence that they ever produced metallic zinc. Therefore they could not

compensate for the loss of zinc on remelting worn brass coins by the addition of brass containing a high proportion of zinc or by the addition of zinc itself. Hence the general downward trend in the proportion of zinc in the coins as they were repeatedly remelted and reissued. Moreover, the analyses indicate that the manufacture of new brass ceased entirely some time before the end of the issue of brass coins. The increasing proportions of tin and lead in the coins of the second century, especially in those issued after the middle of this century, indicate the addition of bronze rather than brass in the remelting of worn coins. Significant also is the more rapid decrease in the proportion of zinc in the coins after the middle of this century. A likely explanation for the stoppage in the manufacture of brass and the consequent later stoppage in the issue of brass coins is the exhaustion of the zinc deposits known to the Romans.

These rather systematic chronological changes in the composition of Roman coinage brass may serve as a rough index for dating various kinds of Roman brass objects. For example, brass coins found in excavations that are illegible because of wear or corrosion could be analyzed and approximately dated by comparing their composition with that of a series of dated coins. Moreover, this might

TABLE 4

Dating of objects other than coins

Object	Source	Zn %	Sn %	Pb %	Probable lower date limit
Fibula	Mainz, Germany	24.45	0.20	none	20 B.C.
Needle	Southwark, England	13.00	1.03	1.07	100 A.D.
Earring	Euboea, Greece	10.87	0.91	0.75	" " "
Fishhook	Putzig, Germany	8.48	2.59	none	150 " "
Fibula	Rhineland, Germany	8.22	2.00	1.70	" " "

make possible the dating of other kinds of objects closely associated with such coins. Since there are strong reasons for believing that all Roman brass was produced in the mints and that the coins themselves were the usual, and perhaps the sole, source of metal for manufacturing other brass objects, it seems likely that these also might be dated in the same way. An interesting possibility is the dating of the many small brass objects that have been found, and are still being found, in the outlying parts and beyond the borders of the area covered by the Roman Empire. It has long been suspected from their weight and chemical composition that these objects were fashioned from Roman coins received in trade by peoples who had less use for the coins than for the various ornamental or useful small objects that readily could be made from them. Some partial analyses of such objects are listed in table 4. Numbers 1 and 3 were analyzed by Fellenberg (1861, 1863), No. 2 by Church (1865), No. 4 by Helm (1895) and No. 5 by Bibra (1869). The dates shown in the table, based on the proportions of zinc, tin, and lead in the objects as compared to those in coins of known date, are suggested lower date limits, that is dates prior to which each of the objects probably could not have been made. The actual dates of manufacture were possibly a few years or even decades later, since it is likely that the coins did not reach the regions where the objects were made until some time after they were struck, and there is also the possibliity that the coins were kept for some time before being fashioned into other objects. In spite of these elements of uncertainty, the

possibility now exists at least for suggesting lower date limits for objects of a kind that previously could not be dated in any way from internal evidence. Obviously this method of dating is safest when applied to a group of similar objects rather than to an isolated individual object which might accidentally deviate widely in composition from the average or normal object of its period.

Analyses of undoubtedly genuine Roman brass objects are also useful for detecting forgeries of such objects. Partial analyses of two forged objects are shown in table 5. The coin was analyzed by Göbel (1842) who apparently did not suspect that it might be a forgery. However, no other example of a coin of this type is apparently known, which in itself should be a cause for suspicion. Its

TABLE 5

Composition of suspected objects

Description	Zn %	Sn %	Pb %
Coin of Julius Caesar	10.50	5.89	1.70
Bust of Germanicus	15.34	10.33	4.45

chemical composition is radically different from that of genuine coins of Julius Caesar, which have been found to contain the highest proportion of zinc of all Roman brass coins and very little tin or lead. Both the type of the coin and its composition agree in indicating a forgery. The metal of the bust was analyzed by the author. The zinc content is lower than that of genuine objects of the early part of the first century A. D., and both the tin content and lead content are very much higher. In fact the composition of both these objects is very different from that of any known genuine Roman brass object.

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Nuclear Physics. *A. Heisenberg.* Philosophical Library, Inc., New York. First English edition, 1953. ix+225 pp. $4.75.

A brief non-mathmematical book on Nuclear Physics designed for readers who have an interest in science but have no great background in physics or mathematics. A history of atomic and molecular theory is given at the outset to give the reader perspective for later discussions.

Even though the presentation is non-mathematical, the lay reader will have some difficulty with the ideas discussed under such topics as Normal States of Atomic Nuclei, Nuclear Force Fields, etc. However, the reader will be rewarded for his efforts by at least having had a brief contact with the ideas and tools of the nuclear physicist.

The chapter on practical applications of Nuclear Physics will be of general interest while no one knows what ultimate uses we may find for nuclear energy, this chapter clearly points out the broad range of possibilities.

An appendix contains a brief historical sketch of research in Germany on the technical applications of nuclear energy. To me, this account by a person so much a part of the story was the most interesting section of the book. EDWARD S. FOSTER, JR.

A MOTILE STRAIN OF *FUSOBACTERIUM POLYMORPHUM*

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The taxonomic system currently used by American bacteriologists (Breed et al., 1948) recognizes four species of the genus *Fusobacterium*. Three of these were originally described by Knorr (1923), while the fourth was described by Weinberg and Prévot (1926) three years later. None of these strains are in the American Type Culture Collection (ATCC), and indeed when our studies on the fusobacteria began, the ATCC had no cultures of this genus at all. Of the several strains we isolated and studied some years ago, only one was thoroughly characterized, and it was deposited with the ATCC in 1951 as *Fusobacterium polymorphum* (ATCC No. 19053) although it differs significantly in certain respects from the original description of the species by Knorr.

In recently reviewing the literature for our revision of the genus *Fusobacterium* in the forthcoming seventh edition of "Bergey's manual of determinative bacteriology", it became apparent that certain of our observations with the strain we characterized as *F. polymorphum* were still unique. We therefore wish to record our observations as documentation for a revision of the species, and to provide a description for the culture deposited with the ATCC.

OBSERVATIONS

The microorganism was isolated from the labial gingival crevice area of the maxillary central incisors of an adolescent male. The gingiva was hyperemic and hypertrophic, apparently largely from poor oral hygiene, but no breakdown of the periodontal membrane was observed. For initial cultivation the inoculum was streaked out upon a series of Difco beef brain heart infusion blood agar plates and incubated 3 days in a screw top jar utilizing the Buchner pyrogallol technique for anaerobiosis. A typical isolated colony was picked upon examination with the dissecting microscope and subcultured into thioglycollate broth (Baltimore Biological Laboratory) enriched with ascitic fluid.

After unsuccessful attempts to continue surface plate cultivation it was necessary to abandon the pyogallol anaerobic technique for the Brewer modification of the Brown jar. Subsequent studies (Hoffman, 1951) established that this strain, as well as the other seven studied, has an absolute carbon dioxide requirement which may perhaps not be satisfied by the conventional pyrogallol technique. However, it appeared that the most serious difficulty with Buchner's method is the evolution of carbon monoxide upon oxidation of the pyrogallol. Attempts failed to obtain surface growth on blood agar plates incubated aerobically, but it was found that a small amount of residual oxygen in the Brewer jar did not hamper optimal growth.

Following solution of the problem of gaseous needs for cultivation, a number of conventional media and a few special media were tested for their ability to support growth. Maximum growth was obtained from several of the more complex media, and especially from those with beef tissue infusion base supplemented with rabbit blood or serum. The potato extract medium of Slanetz and Rettger (1933) was excellent but proved far too time-consuming in its preparation for routine use.

Colonial morphology of the present strain on blood agar during the first three months of subculture consisted predominantly of large, heaped-up, cream colored growth with a somewhat mulberry-like surface. Occasional rhizoid colonies also

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appeared. The colony form then changed completely to a type which had been appearing regularly almost from the first. This was a smooth-edged, slightly bluish-tinged brilliant white colony, convex and quite regular, which was punctiform after 24 hr., about 1 mm. in diameter after 48 hr. (fig. 1) and 1½ to 3 mm. in diameter after 72 hr. Upon close inspection it was seen that the growth presented a peculiar mottled effect of white flecks in a water-clear matrix. With continued incubation this type of colony transformed into a "rough" stage as a result of flat peripheral growth from the colony's edge (fig. 2). The colony in this late phase was 3 to 6 mm. in diameter, and its color was markedly different from early growth. The original convex primary growth changed to light golden yellow, while the secondary peripheral zone was gray. Some time later it was noted that the young colonies no longer presented the brilliant white color, but rather were a comparatively dull gray. The consistency of the growth is butyrous; a slight greening hemolysis develops within 24 hr. of continuous exposure of the plates to air. In early cultivations good growth was accompanied by a strongly putrid odor, but this characteristic tended to disappear with continued transfers.

The gross appearance of broth cultures depends upon the medium used. With Slanetz and Rettger's-potato extract broth, a heavy turbidity initially appears which goes on to form a grayish sediment that settles again quickly following agitation. Microscopic examination of cells from potato extract broth revealed regularly formed single or double rods with characteristic sharply—pointed fusiform shape. The cells in enriched thioglycollate broth (fig. 3) appeared almost as regular and characteristic in morphology as in the potato extract medium. Not infrequently, however, numerous globular extrusions and misshapen cells (fig. 4) were found in the enriched thioglycollate, especially in the earlier cultivations, which appeared similar to the "large bodies" observed by Dienes and Smith (1944) in *Bacteroides*. Long filaments often appeared upon solid media, or in broth cultures subjected to suboptimal conditions. Thus in potato extract broth at pH 10.4 there were formed braids and tangles of long filaments (fig. 5), while in the same broth at pH 5.1 the growth was also filamentous but distinguished by numerous fusiform swellings and by failure to braid (fig. 6).

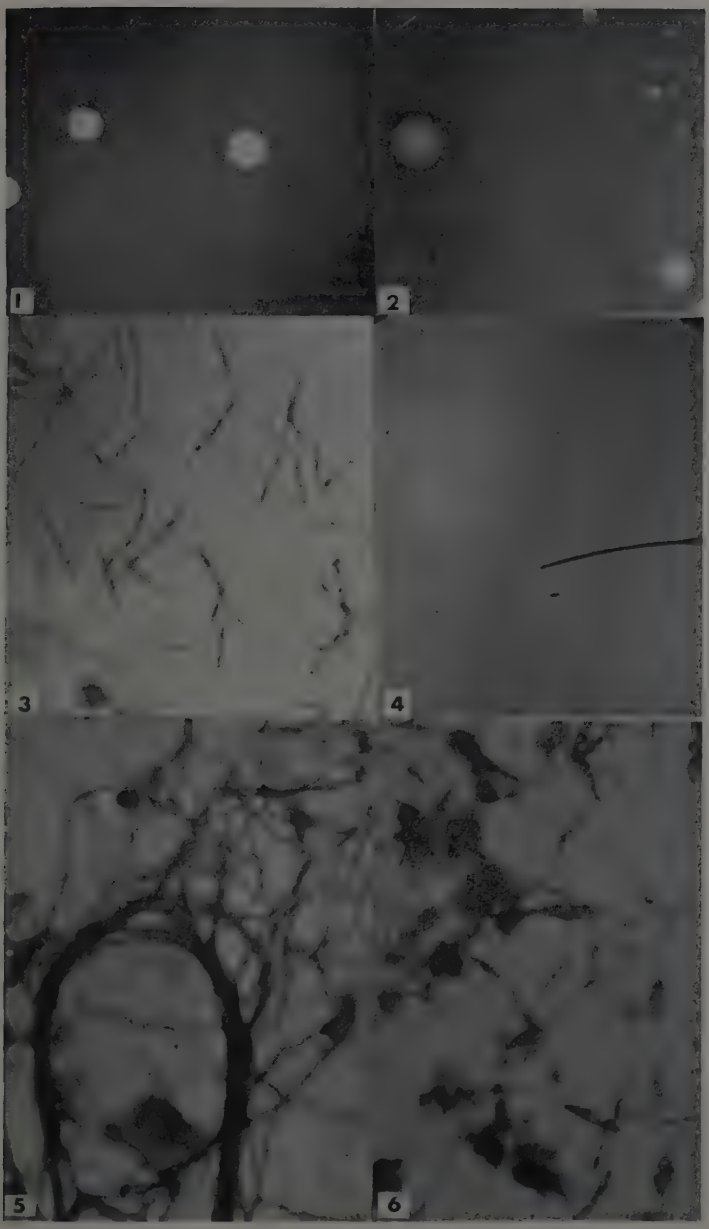
However, cells which appeared to have developed optimally in broth were of uniform size. Upon measurement with a calibrated ocular micrometer it was found that the length ranged from 4 to 13 μ, but most of the cells clustered around 8 to 13 μ. The width was slightly short of 0.5 μ.

The Gram staining reaction (Kopeloff and Beerman technique) was always negative although prominent intracellular granules were present which sometimes gave a positive reaction. Later in cultivation when the granules also gave a consistent negative reaction, they nevertheless counterstained more deeply with the safranine than did the rest of the cell. An intensive cytochemical study of these granules (Hoffman, 1951) later revealed they contain both pentose and desoxypentose nucleic acids.

Wet mounts and hanging drop preparations of enriched thioglycollate broth cultures revealed a slow motion of translation and a distinctive vibratory movement

EXPLANATION OF FIGURES IN PLATE

1. Two day old colonies on rabbit blood beef brain-heart infusion agar.
2. Aged (five day) colonies on blood agar.
3. Three day thioglycollate—ascites culture, methylene blue stain (2000X).
4. Three day thioglycollate culture, "large body" formation, Gram stain (1600X).
5. Filament and braid formation at pH 10.4 in potato extract broth, 38 hour culture, methylene blue stain (1600X).
6. Filament and fusiform swelling formation at pH 5.1 in potato extract broth, 38 hour culture, methylene blue stain (1600X).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of the bacillary ends. Nevertheless, persistent attempts to demonstrate flagella by the conventional staining methods revealed only an elaborated arborized amorphous mass surrounding the entire cell. No evidence for typical bacterial flagella was found.

Of the eight carbohydrates tested (table 1) in potato extract broth, only dextrose, fructose and galactose were fermented. The fermented tubes only showed a drop to pH 6.4 compared to the control pH 6. 9 after 7 days incubation. No gas appeared in the Dunham fermentation tubes. The Barritt alpha-naphthol test for acetylmethylcarbinol was negative after 3, 5 and 6 day readings; a weak evolution

TABLE 1

Characteristics of the present strain compared to the fusobacterial species described in Bergey's manual of determinative bacteriology (Breed, et al., 1948)

Characteristic	*Present strain*	*F. polymorphum*	*F. plauti-vincenti*	*F. biacutum*	*F. nucleatum*
Size	less than 0.5 μ by 8 to 13 μ, long filaments common	0.2 to 0.5 μ by 8 to 16 μ, long filaments common	0.5 to 1.0 μ by 8 to 16 μ (double cells), sometimes short chains or long filaments	0.4 to 0.5 μ by 1.4 to 3.0 μ, sometimes in short chains	1.0 by 4.0 μ spindle shape is marked
Gram reaction	negative	negative	negative	negative	negative
Motility	vibratory and translation	negative	negative	negative	negative
Temperature optimum	37° C	35° C to 37° C	35° C to 37° C	not reported	35° C to 37° C
pH optimum	6.9 to 7.7	7.0 to 8.2	6.8 to 8.0	not reported	6.8 to 8.2
Odor	strongly putrid in early culture	negative	negative	not reported	positive
H_2S	weakly positive	negative	negative	positive	negative
Gas	negative	negative	negative	not reported	negative
Indole	positive	conflicting reports	negative	negative	negative
Gelatin	liquefied	not liquefied	not reported	not liquefied	not liquefied
Carbohydrate fermentations:					
dextrose	acid	acid usually	acid	acid	acid
fructose	acid	acid usually	acid	acid	acid
galactose	acid	not reported	not reported	acid	not reported
inulin	negative	negative	negative	not reported	negative
lactose	negative	negative	acid variable	acid	acid variable
maltose	negative	negative	acid	acid, gas	negative
mannitol	negative	negative	negative	not reported	negative
sucrose	negative	acid usually	acid	not reported	acid variable

of hydrogen sulfide was demonstrated with lead acetate paper suspended in a thioglycollate broth culture for 3 days. Ascites-enriched gelatin was liquefied; the Ehrlich-Bohme test for indole was positive with 48 hr. culture in beef brain-heart infusion broth containing 0.1 percent tryptone. Heated blood slant cultures were catalase negative. Hydrolysis was very slight of 1 percent potato starch in beef brain-heart infusion agar.

The pH growth range was found to be 5.1 to 10.4 with optimum growth between 6.9 and 7.7. The temperature growth range was found to be 31° to 43° C, with the optimum at 37° C.

Cultures in enriched thioglycollate broth remained viable 6 to 7 days at 37° C, 20 days at room temperature and 3 to 4 mo. in the refrigerator at 4° C. Heated blood agar slant cultures were viable for at least 8½ mo., but not 10 mo. at—45° C,

while such tubes with the oxygen absorbed by pyrogallol (Wright tubes) gave viable cultures for at least 22 mo. Lyophilized cultures were viable after 5½ yr., when the last test was made.

It was found that 3-day culture in ascites enriched thioglycollate broth incubated at 37° C survived 24 hr. exposure to oxygen, but not 41 hr. The same culture resisted 52° C for 15 min., 56° C for 10 min., 58° C for 5 min. and 60° C for 2 min.

Neither fibrinolysin nor hyaluronidase could be demonstrated. Pathogenicity could not be demonstrated in white mice with 48 hr. cell suspension from blood agar cultures upon intraperitoneal, intravenous or subcutaneous inoculation. Guinea pig inoculations by the intraperitoneal, subcutaneous and intradermal routes also were negative. Both white mice and guinea pigs were observed for three weeks following inoculation.

DISCUSSION

The characteristics of the microorganism studied here clearly establish it as belonging to the genus *Fusobacterium*, but its species identification is not as clear. Morphology and carbohydrate fermentations resemble those of *F. polymorphum* (see table 1), but its ability to produce hydrogen sulfide and indole, its liquefaction of gelatin, and the evolution of a strongly putrid odor in early culture all indicate a proteolytic activity more pronounced than that of any of the species described in Bergey's manual.

The most distinctive difference in the present strain from the species recognized by the American taxonomists is the peculiar vibratory motion which apparently has not been observed in any other group of bacteria.

The changes which were noted in colonial morphology are extremely interesting. They would seem to indicate an adjustment to artificial media which involved profound changes in the biological characteristics of the strain. We were unable to maintain cultures giving surface colonies characteristic of the early cultivations, and obtained no clues to the factors which may have influenced the transition to the colonial form obtained now.

The marked cellular morphological plasticity we observed seemed to be largely expressed as a reaction to deviations from optimal cultural conditions. When the medium for cultivation was optimum, we consistently obtained cells which corresponded to the description for *F. polymorphum*. This, and a pattern of carbohydrate fermentations consistent with *F. polymorphum*, is sufficient evidence in our opinion to warrant identification of the present strain as *F. polymorphum*. It must be remembered in this regard that Knorr's original description of the species was based upon techniques which are now known to be inadequate; moreover, the original strain apparently has been lost and is no longer available for study. Therefore, rather than increase the number of fusobacterial species, it seems more satisfactory simply to amend the classical description of *F. polymorphum*.

SUMMARY

A motile strain of fusiform bacillus is described. Its cultural characteristics indicate it is *Fusobacterium polymorphum* although it differs significantly from the classical description by possessing a peculiar vibratory motion as well as having movement of translation.

ACKNOWLEDGMENTS

We are indebted to Professor Dorothy Permar, College of Dentistry, The Ohio State University, and to Dr. Louis Griffith, Department of Bacteriology, The Ohio State University, for their generous aid by making the photomicrographs.

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An Outline of Developmental Physiology. *Chr. P. Raven.* (Translated by L. de Ruiter). Pergamon Press, Ltd., London. Mc-Graw-Hill Book Co. N. Y. Agents. 1954. viii+216 pp. $5.50.

This treatise by a distinguished Professor of Zoology in the University of Utrecht and originally published in the Dutch language is now available in this country as an English translation. Professor Raven presents in a concise, lucid style the fundamental observations and critical experiments which support modern concepts of developmental physiology. This author at every point cuts through the details and without digression deals with essentials. Evaluations, interpretations and summarizations are quite adequate and well done.

Starting with the inception of development, various chapters deal with the fertilization of the egg, polarity, symmetry, gradient-fields, chemodifferentiation, the role of nuclear factors, the topogenesis of the embryo, induction, organization, the physiology of later stages of development and of regeneration. A glossary of technical terms is followed by a list of references, made especially helpful by including the most recent contributions of outstanding workers in this field.

Although the author states that this book was written primarily for "readers who, though interested in its subject and having some general knowledge of science, were not acquainted with more than the first elements of biology," this small volume could be used with great profit as a supplementary reference by students in courses in both descriptive and experimental embryology. The reader will gain a broadened perspective and increased understanding in this rapidly advancing field regarding the dynamics of development to a degree scarcely attainable elsewhere in current literature, within so few pages between the covers of a single volume.

JOHN W. PRICE

Elements of Ecology. *George L. Clarke.* John Wiley and Sons, Inc. New York. First edition. 1954. xiv+534 pp. $7.50.

This new text gives stress to general principles of ecology with a balanced treatment of both plants and animals and of aquatic and terrestrial habitats. Examples are frequently drawn from practical problems of conservation of natural resources. Hence, it serves both as an introduction to ecology for college students and as a guide for professional biologists concerned with problems of an ecological nature. Marine organisms are treated equally with those of the fresh waters and land. Concern is given for influence of organisms on environment as well as vice versa. The relationship of all living things to each other and adjustments to their environment is the key note throughout. Mere descriptions of habitats and communities are not given, the emphasis being on dynamics rather than descriptions. Chapter 1 introduces the viewpoint and economic importance of ecology. This is followed by chapters on media, substrata, and water. Then chapters on temperature, light, oxygen and carbon dioxide, and nutrients. Chapter 9 takes up relations within the species including population development and growth. This is followed by chapters on relation between species and on community structure and composition. The last two chapters are devoted to community dynamics—succession and fluctuation and dynamics of the ecosystem, with emphasis on the unity of community and environment and on productivity. There are about 200 carefully chosen illustrations, about 450 selected references, and an index. The unified approach and the synthetic development of the subject should make this book a very successful one in reaching its stated goal of understanding the dynamics of biotic communities. Also, a teacher could reverse the sequence of chapters in a general way and teach the subject from an analytical point of view with the same results.

RALPH W. DEXTER

AGE RELATIONS OF THE MIDDLE DEVONIAN LIMESTONES IN OHIO

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The long continued practice of correlating the Middle Devonian limestones on the east and west flanks of the Cincinnati arch in Ohio has been questioned by more recent workers. This doubt has arisen partly because of a better understanding of stratigraphic relationships with rocks of similar age in adjoining states, partly on a more detailed knowledge of the lithologic conditions, but mainly because of a better understanding of the fossils within the formations.

The "Columbus" limestone of northwestern Ohio west of the anticline is recognized now as a continuation southward of the Dundee limestone of the southern peninsula of Michigan, and the approximate age of the Delaware limestone east of the anticline in Ohio and southwestern Ontario. It is therefore younger than the Columbus limestone which lies below the Delaware limestone in these latter regions.

The purpose of this paper is to bring together data already known on these Devonian limestones in this State, and to add further information, particularly on the faunas, which might help to underwrite existing opinions on the subject.

OUTCROP AREAS

The Middle Devonian limestones of central and northcentral Ohio consist of two formations: the Columbus limestone below, and the Delaware limestone above. They crop out east of the Cincinnati anticline in a narrow, north-south belt, about 20 miles across at the greatest width which is in Wyandot and Crawford counties (fig. 1). The beds dip gently east to southeast, and are thickest in central Ohio, notably in Franklin and Delaware conuties, where the Columbus attains a thickness of 105 ft., and the Delaware about 40 ft. Southward from the city of Columbus in Franklin County, the outcrop extends for 25 mi. to the southern part of Pickaway County, where the beds become concealed by the overlapping upper Devonian Olentangy and Ohio shales.

Northward from central Ohio there is a continuous band of outcrop to the southern shore of Lake Erie, and detached exposures occur in the adjoining Johnson and Kellys Islands. North of the international boundary the furthest known northern outcrop up to 1951 was on Pelee Island, where Stauffer (1915, p. 206–213), reported about 28 ft. of Onondaga limestone in Captain Jack McCormick's quarry, at the northwest corner of the island. However, Ehlers and Stumm (1951) reported an exposure of the Columbus limestone in the Chemical Lime Company's quarry near Ingersoll, Ontario (fig. 1). This exposure consists of 15 ft. of gray to buff-gray dolomitic limestone with many fossils, and 1 ft., 2 in. of calcareous sandstone below with few fossils. The sandstone rests with disconformable contact on the Lucas formation of the Detroit River group. The contact of the limestone above with the overlying Delaware limestone is not seen in the quarry, but is believed to be a short distance southwest of the present quarry wall. On the basis of lithology and fossils Ehlers and Stumm interpret these rocks as the upper part of the Columbus formation (zone H), and that they rest disconformably on the underlying Lucas formation as a result of stratigraphic overlap from the south. The presence of the sandstone suggests a nearby shore since the outcrop is very close to the northern limit of the limestone.

A second area of outcrop in Ohio, of much smaller extent, occurs just a little east of the crest of the Cincinnati arch. This is the Bellefontaine outlier, about 40

mi. northwest of Columbus (fig. 1). The outlier is an elliptical elevated area, of about 160 sq. mi., which extends from the northern part of Logan County south to the village of Cable in Champaign County, a distance of about 23 mi. It is rimmed by the Columbus limestone, which is overlain unconformably by the black Ohio shale. The uneven character of the unconformity is well shown in the quarry of the East Liberty Stone Company, one mile west of the town of East Liberty,

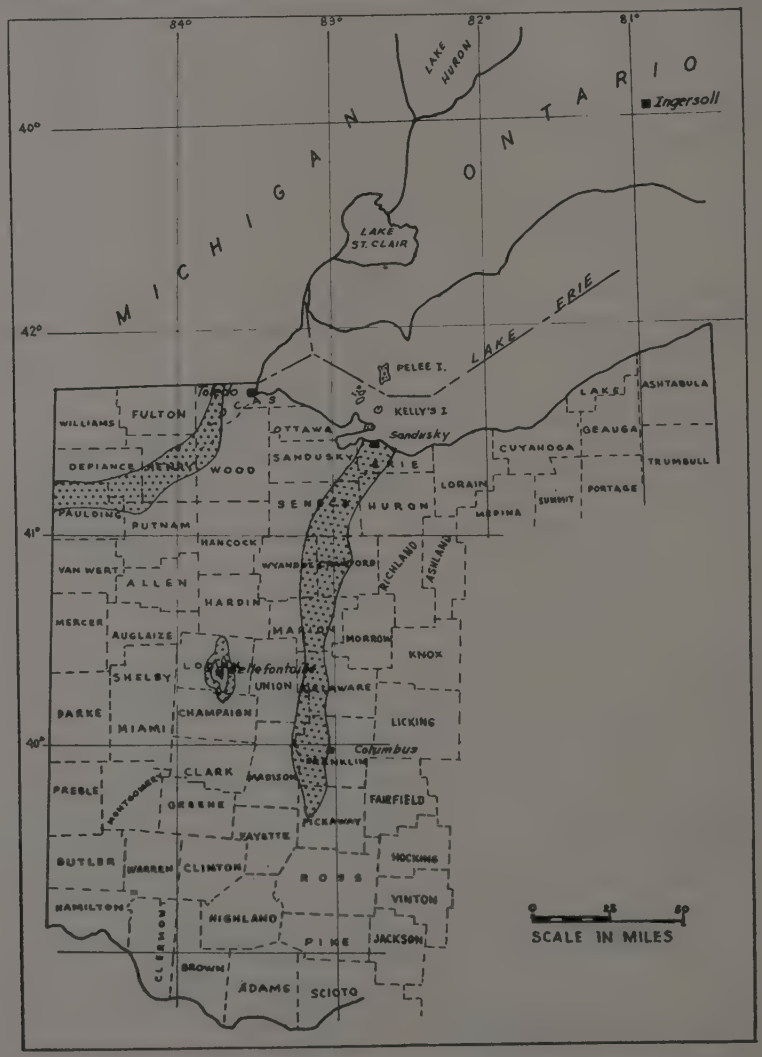

FIGURE 1. Index map showing outcropping areas of Devonian limestone in Ohio.

where about 39 ft. of Columbus limestone is exposed. A thin, well-developed bone bed accumulation fills in much of the irregular surface of the limestone. The total thickness of the limestone is approximately 80 ft. The Delaware limestone and Olentangy shale are apparently missing from the section.

A third region of Devonian limestone is in the northwestern part of the state, west of the Cincinnati arch. A crescent-shaped belt of outcrop extends southward from Michigan into Lucas and Henry counties, and thence swings westward in the vicinity of Antwerp, Paulding County, into Indiana (fig. 1). Because of the flat character of this interior lowland area, and the general covering of glacial drift, the outcrops are very scarce, and the geology has to be interpreted largely from quarry sections. These are best known from Lucas County (fig. 2).

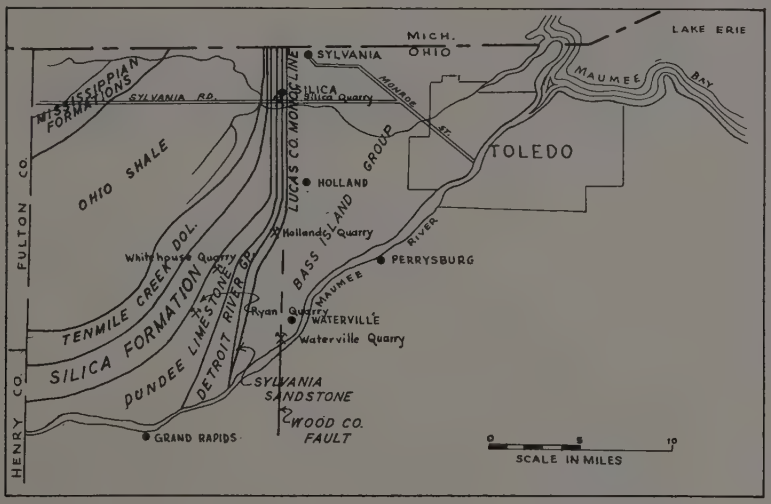

FIGURE 2. Map of Lucas County showing areal extent of several rock units.

Three Middle Devonian formations are recognized in this northwestern area: The Dundee ("Columbus")limestone below, overlain by the Silica formation and Tenmile Creek dolomite above. Originally Stauffer (1909, p. 149) introduced the Michigan term Traverse into the Ohio section for the rocks of northwestern Ohio lying between the top of his "Columbus" limestone and the Ohio shale. The "Columbus"—Traverse contact of Stauffer was at the base of zone 8 of the Whitehouse quarry section of figure 3. But the top of the Dundee, as now used, is at the top of zone 10 of the Whitehouse quarry section. That is zones 8, 9, and 10 at Whitehouse, totaling 4½ ft. are moved from the base of the Traverse of Stauffer to the top of the Dundee ("Columbus"). Figure 3 shows that the equivalent units at Silica, zones 4, 5, and 6, total 11 ft.

REVIEW OF TERMINOLOGY

First mention of the Ohio limestones goes back to the reports of the earliest Geological Survey in Ohio (table 1). In these early surveys the Devonian limestones were not differentiated from the older Silurian formations below, and the Cliff formation of Locke (1838), included the Silurian beds also. It was Hall (1842) who recognized the upper part of the Cliff limestone as a continuation of

TABLE 1

Historical Review: Classification of Middle Devonian Limestones of Central and Northcentral Ohio

Locke 1838	Hall 1843	Mather 1859	Newberry 1873	Winchell 1874	Orton 1878	Whitfield 1880	Prosser 1905	Swartz 1907	Stauffer 1909	Westgate 1926 Delaware Co.	Cooper, et al. 1942		Wells 1947	Zones of Stauffer (1909) Modified by Wells (1947)
Clift limestone (included Silurian limestone.)	*Corniferous limestone* (first named and identified with the New York Corniferous by Hall. Included present Columbus and Delaware limestones.)	*Columbus limestone* (used Columbus to replace Corniferous in "Report on State House Artesian Well at Columbus.")	*Sandusky limestone* (Included upper part of Columbus limestone of Mather.)	*"Delaware limestone"* (Did not suggest formational value—recognized Hamilton age of fossils.)	*Delaware limestone* (Suggested name to replace Sandusky Ls. of Newberry in Central Ohio.)	*Delaware limestone* (Confirmed Hamilton age as suggested by Winchell by discovery of Marcellus fossils in lowerpart.)	*Delaware limestone* (Further consolidates position of Delaware, and shows that most of Newberry's Sandusky Ls. in N. Ohio is Columbus Ls.)	*Delaware limestone* (Was first to prove term Sandusky Ls. invalid in personal communication with Prosser.)	*Delaware limestone* Zones I - M (Recognized 5 zones in central Ohio.)	*Delaware limestone*	L. Erian (Cazenovia)	*Delaware limestone* *"Hadrophyllum Zone"*	*Delaware formation* Zones I—M of Stauffer.	*Delaware formation* M—Includes 2 minor Bone beds L—Zone of *Hadrophyllum d'Orbigni* (3rd Bone bed) K—Zone of *Grammysia bisulcata* J—Zone of *Tentaculites scalariformis* I—Zone of *Martiniopsis maia*
					Bone Bed									
			Columbus limestone (First to separate the limestones, and the lower greater part was retained as Columbus.)	**Corniferous limestone*	*Columbus limestone* (Thought limestones probably covered same age as Corniferous and Hamilton of New York but didn't definitely correlate them. Recognized and described for first time Bone Bed top of Columbus.)	*Columbus limestone*	*Columbus limestone*	*Columbus limestone* Venice member Marblehead member Bellepoint member (Correlated north central and central Ohio sections, recognized 3 members of Columbus Ls.	*Columbus limestone* Zones A H (Recognized 8 zones in central Ohio.)	*Columbus limestone* Klondike member Heavy Ls. Coral layer Bellepoint member (Term Klondike used to replace Delhi of Winchell = U. Zone E through H of Stauffer. Zone C = Coral Zone A–B = Bellepoint)	U. Ulsterian (Onesquethaw)	*Columbus limestone?*	*Columbus formation* Delhi member (Klondike) = Zones E—H of Stauffer Eversole member (Zone D) Bellepoint member (Zones A - C) Zone D (Chert Zone) named Eversole and given member rank.	*Columbus formation* H—Zone of *Nucleocrinus verneuili* (Includes 1st and 2nd Bone beds) G—Zone of *Goldringia cyclops* (cephalopod zone) F—Zone of *Brevispirifer gregarius* E—Zone of *"Spirifer" macrothyris* D—Zone of *Laevidentalium martini* (gastropod and chert zone) C—Coral zone B—Few fossils A—Conglomerate zone

*In 1903 the name Onondaga was adopted to replace *Corniferous* in New York State. Clarke, N. Y. State Museum, Handbook No. 19, pp. 8, 21, 22.

the Helderberg group of New York State, and in the following year named it the Corniferous limestone from exposures in the vicinity of Columbus.

The name Columbus limestone was used first by Mather (1859) in a communication to the State. The term was used to replace Corniferous limestone without any explanation.

Further study on the limestones was continued during the work of the second Geological Survey of Ohio under the direction of Dr. J. S. Newberry, Chief Geologist. The distribution of the limestones was shown on the "Preliminary Geological map of Ohio" by Newberry in 1869 and a short discussion of their occurrence, lithology, and fossils was given (p. 17, 18). Newberry used the term "Corniferous," thereby accepting Hall's identification. However, a more detailed report is given in the first volume of the Geological Survey of Ohio (Newberry, 1873, p. 142–149), where Newberry recognized two divisions: an upper one, which he named the Sandusky limestone, and mentioned as being quarried at Sandusky and Delaware, and which he described as a thin-bedded, blue limestone, from 15 to 20 ft. in thickness; and a lower one, the Columbus limestone, which he said supplied the stone from which the State Capitol in Columbus is built. Newberry noted the occurrence of characteristic Hamilton fossils in the Sandusky limestone such as *Mucrospirifer mucronatus* (Conrad), and *Cyrtina hamiltonensis* (Hall), but concluded that since the larger number were Corniferous in age both limestones should be correlated with the Corniferous of New York.

He listed and illustrated some characteristic species from the Corniferous limestone in the following order: *Platyceras* (*Platyceras*) *dumosum* Conrad, *Pentamerus aratus* Conrad, *Spirifer raricosta* Conrad, *Lucina? proavia* Goldfuss, *Paraspirifer acuminatus* (Conrad), *Nucleocrinus verneuili* Troost, *Megastrophia hemispherica* (Hall), *Brevispirifer gregarius* (Hall), and *Conocardium trigonale* Conrad.

The foregoing are all Columbus limestone species, apart from *Spirifer raricosta* which is found in the Delaware limestone. Newberry pointed out that the most striking fossils of the Corniferous group are fishes, and he discussed, but did not illustrate them.

The Corniferous age of the Devonian limestone in northwestern Ohio was also recognized by Newberry, and likewise the limestones in the Bellefontaine outlier where he speaks of them as forming "part of the Devonian island in Logan County." (p. 143).

The term Delaware was first used for the upper part of the Corniferous in Ohio by Winchell (1874, p. 293, 294) in which he refers to the "Delaware stone", in one place, and the "Delaware limestone" in another, apparently not thinking of the rocks in the light of a formation. He described the geology of several counties in central and northwestern Ohio and stressed the Hamilton aspect of the fossils in this upper limestone in both these places. He used the name "Hamilton group" in the legend of the geologic maps of Delaware, Paulding, and Henry counties (facing p. 272, 336, and 416).

Winchell (1875, p. 59) correlated the Devonian outcrops in Sandusky, Delaware, Marion, and Sec. 17, Defiance, Defiance County, Ohio, with the Hamilton blue limestone in the region about Thunder Bay, Lake Huron, and near Clarlevoix, in the northern part of the Lower Peninsula of Michigan. Newberry still objected to Hamilton age for the Sandusky limestone beds.

Orton (1878, p. 606), first used the term Delaware as a formational term for the upper 32 ft. of blue limestone exposed near the town of Delaware, to replace Newberry's older name of Sandusky limestone in central Ohio. He retained the name Columbus limestone for the lower part, and was the first to recognize and describe the 6-inch layer of bone bed material at the top of the Columbus. This, incidentally, is one of the best developed bone beds in the Columbus limestone in central Ohio, and is designated Bone Bed No. 2 in more recent literature. Where

well developed, this unit is most helpful in determining the boundary between the two formations. Orton thought the two limestones probably covered at least part of the time in which the Corniferous limestone and Hamilton group were forming.

The next significant development toward a closer correlation with the New York section was in 1878 when Professor R. P. Whitfield visited Franklin County, and recognized a thin bed of dark brown shale at the base of the Delaware limestone at Slate Run and further north along the Scioto River just across from the town of Dublin. At the first locality he found two small species of inarticulate brachiopods, *Discina minuta* Hall and *Lingula manni* Hall, and *Leiorhynchus limitare* (Vanuxem). At the second locality, *L. limitare* and *Orbiculoidea lodiense* (Vanuxem). These are typical Marcellus species, *D. minuta* and *L. limitaris* being restricted to it. Recently the writer has found *Leiorhynchus limitare* and a large species of *Lingula* about 20 ft. above the base of the formation at the now abandoned quarry of the Miami Stone Company about 3 mi. north of Bartholomew Run along the Olentangy River in Delaware County.

Whitfield's discovery seemed to confirm Winchell's earlier opinion of Hamilton age of the Delaware limestone, and he pronounced it the equivalent of the Marcellus shale of New York (Whitfield, 1880, p. 297, 298). Later Whitfield (1883) published a list of the fossils found in the shales, and described two new species. Descriptions of all the species (16) were published in the seventh report of the Geological Survey of Ohio (p. 441–452). Only one of these species, *Leptaena rhomboidalis* (Wilckens), occurs in the Columbus limestone below. The extremely abundant *Tentaculites scalariformis* Hall was not included in the list. Whitfield listed 6 species restricted to the limestone above the bone bed which included 4 Hamilton species: *Spirifer ziczac* Hall, *Cornellites flabella* (Conrad), *Nyassa arguata* H. and W., and *Grammysia bisulcata* (Conrad).

Prosser (1905, p. 413–422) outlined in chronological order the contributions made by various geologists on the Devonian limestone problem up to that time, and in some detail discussed the Delaware limestone. His main contribution was to establish the fact that most of Newberry's Sandusky limestone in northern Ohio, belonged in the lower instead of the upper division of what he called the "Corniferous limestone." Prosser gave due credit to Dr. Charles K. Swartz of Johns Hopkins University, whom he says in 1903 "correctly determined the stratigraphic position of the limestones in the city of Sandusky, and correlated them with the Columbus limestone of central Ohio." (Communication made to him by letter, p. 441). This was primarily on faunal grounds. Swartz reported about 87 percent of the species from the Columbus limestone in the Columbus vicinity as represented in the part of the Sandusky formation which he referred to as the Columbus in the Lake Erie region. Prosser concluded that the term Sandusky should be dropped since it involved two formations. In place of it he proposed the name Delaware to conform with the nomenclature of rocks of similar age further south in the state.

Two years later Swartz (1907) published a paper in which his views as already transmitted to Prosser were included. He presented evidence, mostly faunal, that the Sandusky and Delaware limestones were not equivalent, that the Sandusky limestone was partly Columbus and partly Delaware in age, and therefore could not be considered as an independent unit. He divided the Columbus limestone into 3 members on lithologic and faunal grounds, naming them from the regions where they were best exposed. The members from the oldest to the youngest are: Bellepoint, Marblehead, and Venice.

Probably the most comprehensive and detailed study of the Ohio Middle Devonian limestone was made by Stauffer (1909). Although this work deals primarily with the limestones, the Olentangy and Ohio shales are also included if they were present in the regions where his sections were made. Numerous

sections are included in the volume, some well known ones from earlier workers, and many new ones of his own. Descriptions of the lithology, stratigraphy, and paleontology are given in much more detail than in any previous publication. The formations are divided into zones on a paleontological and lithologic basis.

In the central area of outcrop, more particularly in Franklin County, alphabetical letters were used by Stauffer for the various zones where they could be correlated with a fair degree of accuracy. Eight zones, A-H, were established for the Columbus limestone, and 5 zones, I-M, for the Delaware limestone. Northward from the village of Stratford which is 3 mi. south of Delaware, the faunal zones could not be correlated so readily from section to section, so the zones were numbered, the numbers not being correlative necessarily from section to section. A similar system was used for the northwestern part of the State, and for the Bellefontaine outlier which is assumed to be a detached portion of the central area cut off by preglacial erosion. This work brings together for the first time names of all the known fossil species up to that time from the Columbus, Delaware, and Olentangy formations, and in addition a few new ones were added and described. Stauffer's work has been the principal source of information for all subsequent workers on the Devonian limestone formations in Ohio.

Westgate (1926, p. 22, 23), adopted a four-fold subdivision for the Columbus limestone based largely on physical characters, because he believed that unless one knew the fossils thoroughly Stauffer's zones could not be used. He named the upper division the Klondike member, replacing the term Delhi originally used by Winchell (1874, p. 296) for these beds. The Klondike member according to Westgate includes zones E (upper part), F, G, and H of Stauffer in Franklin County, and most of the Venice and Marblehead members of Swartz (1907). The lowest division was named the Bellepoint member after Swartz (p. 63) from the village of that name. It comprises zones A and B of Stauffer.

The two intermediate divisions were not named. The first division below the Klondike (6-foot zone), was designated the "heavy limestone layer," and correlated with the lower part of Stauffer's zone E. Below this was the "coral layer," which is zone C, or the coral zone, of both Franklin and Delaware counties. Westgate did not recognize the chert zone (D) in Delaware County north of White Sulphur. No zonal divisions for the Delaware formation were made.

Cooper (1942) questioned the stratigraphic position of upper Onesquethaw for the Columbus limestone, but accepted lower Cazenovian for the Delaware.

In a paper title "Provisional Palaoecological Analysis of the Devonian Rocks of the Columbus Region," Wells (1947) introduced the name Eversole member for Zone D (chert zone) of the Columbus limestone, and designated it "zone of *Laevidentalium martini*," in reference to this characteristic species of the zone. He reinstated the old name Delhi of Winchell for the upper division of the Columbus limestone, designated Klondike by Westgate, including in it zones E-H of Stauffer. His lower division, the Bellepoint member, was extended to include zones A-C. Wells' paper is the most detailed and critical biostratigraphic analysis of the Devonian rocks in the Columbus region that has been published.

As previously mentioned Newberry recognized the "Corniferous" age of the Devonian limestones in northwestern Ohio, and stressed the Hamilton aspect of the fossils in the upper part, and Winchell correlated them with the central and northcentral outcrops, and with those of southeastern Michigan. Later when a division into two formations, Columbus limestone and Delaware limestone, was made on the east side of the anticline, the names were automatically carried over to the northwest although the correct position of the boundary between the two formations was doubtful.

An examination of table 2 shows that Stauffer recognized two Middle Devonian formations in northwestern Ohio, the Columbus limestone and the Traverse formation. On the basis of lithology and fossils he correlated the lower formation

with the Columbus limestone east of the anticline in Ohio as earlier geologists had done. For the upper formation, however, he introduced the Michigan term Traverse into the State, recognizing the rocks as an extension of the upper part of that group from southeastern Michigan. On the basis of the many Hamilton fossils he considered the formation to be the equivalent of the Delaware and Olentangy formations east of the Cincinnati arch in Ohio.

Stewart (1927) accepted the correlation of the two limestones on either side of the anticline, and named the Silica shale for a unit in the lower part of Stauffer's Traverse not recognized by him.

TABLE 2

Historical Review: Classification of Middle Devonian Formations of Northwestern Ohio

Stauffer 1909	Stewart 1927	Bassett 1935	Cooper, et al. 1942		Ehlers Stumm Kesling 1951
Traverse formation			L. Tioughnioga	**Tenmile Creek dolomite*	**Tenmile Creek dolomite*
(Stauffer introduced Michigan term; regarded rocks as upper Traverse and equivalent in time to Delaware and Olentangy formations of central Ohio; and the fauna as Hamilton in age.)	(Named by Stewart for 10 ± ft. of shale with Hamilton fauna in lower part of Stauffer's Traverse.)		Casenovia	*Upper Silica shale*	*Silica formation*
	Silica shale			*Lower Silica shale with Paraspirifer*	
				"Blue bed"	
Columbus limestone	*Columbus limestone*	*Columbus limestone*		*Dundee limestone*	*Dundee limestone*
(Was correlated with Columbus limestone of central and north central districts on basis of lithology and fossils.)		(Bassett correlated the Columbus limestone of northwestern Ohio with the Dundee of Michigan and with the "Upper Columbus" of Carman's unpublished manuscript.)		(= *Delaware limestone*)	(= *Delaware limestone*)
Detroit River Group	*Detroit River Group*			*Detroit River Group*	*Detroit River Group*

*Named by Carman (unpublished manuscript).

For the first time Bassett (1935) correlated the Dundee as exposed in the Sibley quarry in southeastern Michigan, with the "upper Columbus" of the Silica and Whitehouse quarries in Lucas County, northwestern Ohio, on the basis of lithology and similarity of fossils. Bassett's published sections from the "upper Columbus" were from Carman's unpublished manuscript. The younger age of the northwestern Columbus limestone as compared with the central Ohio Columbus was apparently firmly established.

In the chart of Cooper et al. (1942), the Dundee position of the northwestern Ohio "Columbus limestone" is recognized, and its equivalence to the Delaware limestone. The name Dundee appears for the first time in print for the Ohio exposures. These in turn approximate the stratigraphic position of the Marcellus shale of the Appalachian Mountain region. In regard to the chart as a whole,

however, the authors caution the reader not to accept the correlations as final and fixed, but that "it is a statement of existing knowledge only."

Finally, Ehlers et al. (1951) in their publication, prepared as a guide book for the Geological Society of America, give in detail the zones of the Ohio Dundee limestone, give the Silica shale formational rank, and extend it downward to include the "Blue limestone" of Carman (unpublished manuscript).

DESCRIPTION AND CORRELATION OF THE LIMESTONES

The provisional classification of the Middle Devonian rocks in Ohio as presently recognized is shown in table 3 and is the result of the collective efforts of past and contemporary workers. Some of it may be only of a temporary nature, particularly in the smaller units. The three formations with which we are especially concerned in this study are the Columbus, Delaware, and Dundee limestones.

TABLE 3

Provisional Classification of the Bedrock Divisions of the Middle Devonian Rocks of Ohio As Presently Recognized

Series	Stages	Bellefontaine Outlier	Central Ohio	Northcentral Ohio	Northwestern Ohio
Erian	Taghanic	Upper 10 ft. of Columbus may represent Delaware time or younger.	[1]*"Olentangy shale"*	*Prout limestone*	*Tenmile Creek dolomite*
	Tioughnioga			*Plumb Brook shale*	*Silica formation* (includes "Blue ls.")
	Cazenovia		*Delaware limestone* Zones I - M	*Delaware limestone*	*Dundee limestone*
Ulsterian	Onesquethaw	*Columbus limestone* Delhi member?	*Columbus limestone* Delhi member Zones E - H Eversole member? Zone D Bellepoint member Zones A - C	*Columbus limestone* Venice number Marblehead member Bellepoint member	Detroit River Group
		Detroit River Group		Detroit River Group	

[1]Position and relationship of Olentangy blue shale to upper Devonian Ohio black shale not certainly known. It is probably upper Devonian in age.

Columbus Limestone

In the central belt of outcrop are exposed the Columbus and the Delaware limestones. The older of the two formations, the Columbus limestone, is the thicker of the two, and in Franklin County reaches a thickness of 105 ft. At the base it rests disconformably upon the upper Bass Island series (Silurian), and the contact may be observed 7 mi. north-northwest of Columbus on Mill Creek near Bellepoint. Evidence of this erosional break may be seen in the one-foot layer of conglomerate at the base of the Columbus which contains large and small water-worn pebbles of the Bass Island rocks in a Columbus limestone matrix. The upper contact is marked by a bone bed layer, from 3 to 15 in. thick, which locally may be absent. Where absent, changing lithology and fossils may be used fairly satisfactorily to determine the boundary.

Two major distinct lithogic (lithotope) facies are commonly developed in the Columbus limestone. The lower part, which comprises less than half of the formation (zones A-C of Stauffer) is a massive, brown limestone, with two systems of well-developed oblique joints. This is a dolomitic limestone with a high percentage of magnesium carbonate. Fossils are scarce and poorly preserved, except in the upper 4 ft. (zone C), which constitutes a coral and stromatoporoid biostrome. Simple horn-shaped corals of the family Zaphrentidae, and large branching masses of the colonial family Favositidae, make up most of the layer. Large, cylindrical specimens of *Siphonophrentis gigantea* are among the most striking fossils in this coral community (biocoenose).

The upper half or more of the Columbus limestone (zones D-H of Stauffer), is typically light gray in color, apart from the top layers (zone H) which is usually bluish. Rock layers are thinner as a rule than in the lower division, although portions, such as zone G, may be very massive. Chert is present in considerable abundance, either in lenses, or in more or less continuous layers such as developed in zone D, known locally as the chert or gastropod zone. In this zone the chert is very fossiliferous, and the external markings of the original shells are beautifully preserved in the chalky shell replacement. The limestone is surprisingly pure, in places nearly 94 percent pure calcium carbonate. Much of the rock is crystalline or subcrystalline in structure. Fossils are distributed all through the limestone, certain layers packed together in a thanacoenose assemblage of various origins.

The same dual lithologic facies is recognized in the northern portion of the central belt. The limestone is thinner there though, and attains a thickness of approximately 60 ft. Only the upper part of the Columbus limestone is present, much of the lower part (zones A-D) apparently disappears as a result of overlapping of the higher beds northward. The bone bed at the top is very sketchily developed as compared with central Ohio. The best exposures are quarry sections, notably at Sandusky, Marblehead, and Kelly's Island.

The subdivsions of the limestone in this northern area involved the problem of the Sandusky formation already discussed. Three divisions, established by Swartz (1907), and the lithologic and faunal features are:

1. *Venice member* (zone H of central area).—The rock is a massive blue limestone with little chert, and an intermittent bone bed at the top. Two fossil horizons below the bone bed were designated the "*Spirifer*" *duodenarius* horizon, and the upper *Paraspirifer acuminatus* horizon because of the abundance of these brachiopod species. Additional characteristic fossils of the latter horizon are: *Nucleocrinus verneuili* (Troost), *Eridophyllum verneuilanum* (Edward and Haime), and *Platyceras* (*Platyceras*) *dumosum* Conrad. The equivalence of this fauna to that of the upper Delhi (zone H) in central Ohio was established by Swartz (1907, p. 64) when he estimated that 87 percent of the species were represented in the corresponding horizon there. Likewise wave markings occur at the base of these rocks in both regions.

2. *Marblehead member* (zones E-G of central area). —The rock is a gray, fossiliferous limestone. Three spiriferid horizons, not all in one section, were distinguished by Swartz: lower *Paraspirifer acuminatus* faunule (in north), *Brevispirifer gregarius* faunule, and "*Spirifer*" *macrothyris* faunule (in south).

In central Ohio *P. acuminatus* (Conrad) is especially characteristic of zone H, but also occurs in zone G, but not to the extent of constituting a faunule. *B. gregarius* (Clapp) is the common species of zone F, but has a range from E through G. "*S.*" *macrothyris* (Hall) is the common spiriferid of zone E, but extends down into D. In other words an equivalence with the lower two-thirds of the Delhi is evident. The chert zone D (Eversole member) is not recognized in the northern area.

3. *Bellepoint member* (upper zone B and C of central area).—Only 6 ft. of a

brown, dolomitic limestone are included in this division. It is typified by many corals, and has a one-inch sandy layer at the base. The dolomitic phase of the Columbus limestone is much thicker in central Ohio.

In the Bellefontaine outlier the Columbus limestone is known from various exposures along runs and in quarries. As mentioned previously the total thickness is approximately 85 ft. In general the limestone is more dolomitic than in the Franklin County region, and that is one reason why Stauffer regarded it as probably equivalent to the lower Columbus of that area. However, this is probably not the case because typical fossils of upper Columbus zones are found in the formation here. Moses (1922, p. 20) recognized three distinctive divisions based on lithology and fossils as follows:

1. *Upper Division.* Forty to 45 ft. of gray-brown, subcrystalline to crystalline limestone, interbedded with chert in the upper three-fourths. The upper 10 ft. at the East Liberty quarry is a hard blue limestone, with many fish teeth and plates. This is a local arenaceous layer, overlain by the East Liberty bone bed of Wells (1944, p. 280), which may represent Delaware time of the central area. Corals are common throughout a large part of the formation, of which *Zaphrentis phrygia* (Rafinesque and Clifford) and *Favosites turbinatus* (Billings) are the most common. The presence of *Paraspirifer acuminatus* (Conrad) suggests a position probably not below zone G of the central district.

2. *Middle Division.* Thirty feet or less of massive, hard, gray, dolomitic limestone, with some chert nodules; in general highly fossiliferous. The occurrence of *Brevispirifer gregarius* (Clapp) suggests a stratigraphic position relative to zones E and F of the central area. The thickest section is on the north branch of a run one mile north of the north edge of East Liberty where 22 feet are exposed. This is near the base of the formation here because contact with the underlying Detroit River series is visible a few hundred yards to the north in a small quarry and ravine at approximately the same elevation, i.e., 1,165 ft.

3. *Lower Division.* About 20 ft. of dark gray, thick-bedded fossiliferous limestone, exposed only at Cable and Middleburg in the southern part of the outlier. At Cable Stauffer (1909, p. 98) recognized 23 ft. of Columbus limestone, divisible into 6 zones. The upper zone 6, a massive, 3-foot layer of very fossiliferous, gray limestone, probably belongs in the middle division because of lithologic and faunal features. Fossils in this zone which suggests this higher stratigraphic position are: *Stropheodonta demissa* (Conrad), *Megastrophia hemispherica* (Hall), *Pholidostrophia iowaensis* (Gwen), *Brevispirifer gregarius* (Clapp), and *Paracyclas proavia* (Goldfuss).

The 3-foot layer which comprises zone 4, contains much white, extremely fossiliferous chert. The most distinctive and abundant species are: *Pleurodictyum* (*Procteria*) *michelinoides* (Davis), and *Odontocephalus aegeria* (Hall). These are not known in central Ohio.

Delaware Limestone

The Delaware limestone is the upper of the two Middle Devonian limestones, and reaches an average thickness of about 36 ft.. in central Ohio; the maximum thickness in the type area at Delaware is estimated at about 45 ft. Where the bone bed (No. 2) at the top of the Columbus below is well developed the lower contact of the Delaware limestone is easily determined. But where the bone bed is lacking, the thin shaly layers which are always developed above the bone bed, help to determine the lower limit of the formation. The presence of the brachiopods *Leiorhynchus limitare*, *Orbiculoidea lodiense*, and *Discina minuta* was the reason why Winchell determined the Delaware as Marcellus in age as mentioned previously. The contact with the Olentangy shale above is usually definite and easily recognized.

The Delaware limestone is variable in its lithology and appearance, but is typically a blue limestone which weathers to a brown color, and is interbedded with thin brown shale and chert layers. The chert is black, gray, or white in color, and commonly is not very fossiliferous. It gives the rock a mottled appearance in many of the outcrops. In general it is a thinner-bedded formation than the Columbus, but it is likely to be massive where the shale and chert are missing. Fossils are abundant, although unevenly so. The formation is well exposed along the Scioto River valley, and in the various runs tributary to it and to the Olentangy River valley.

Stauffer divided the Delaware limestone into 5 zones (I-M) partly on lithologic differences, but mostly on changes in the fossil content (table 1).

The Delaware limestone of northcentral Ohio constitutes the upper part of the Sandusky formation of Newberry (1873). It is the "upper blue limestone" of Swartz, and he describes it as a blue limestone with chert from 6 to 15 ft. above the base, and having a thickness from 31 to 47 ft. More detailed information by Stauffer (1909) shows interbedded layers of impure limestone, having a brown or bluish-brown color, and occasional bands of chert; crinoidal layers occur at intervals, and occasional crinoidal shale partings. The contact with the Plum Brook shale above is usually sharp and definite. Zones are not distinguished as in central Ohio, and the basal shaly layer is missing. However, the two areas share many fossil species in common. Some of the more significant ones are: *Hadrophyllum d'Orbigni* Edwards and Haime, *Leiorhychus limitare* (Vanuxen), *Martiniopsis maia* (Billings), *Ambocoelia umbonata* (Conrad), and *Tentaculites scalariformis* Hall.

Rocks of Delaware age are not recognized in the Bellefontaine outlier.

Dundee Limestone

As previously mentioned the Dundee limestone of northwestern Ohio is the southward extension of the same formation in southeastern Michigan. Because of faunal similarities the Dundee is correlated with the Delaware limestone on the east side of the Cincinnati anticline in Ohio and southwestern Ontario. In Ohio the Dundee has a stratigraphic position between the Detroit River group below, and the Silica formation above (Table 3). The lower contact is disconformable, but the upper is transitional and not so easy recognizable. Establishment of the boundary is made on the basis of fossils. It is now placed at the base of the "Blue" limestone layer (Ehlers et al., 1951, p. 18), an 8-foot bluish-gray limestone tentatively named by Carman (unpublished manuscript), and included in Bassett (1935, p. 437). The "Blue" layer has in its lower part a great abundance of *Chonetes coronatus* Conrad, and in fewer members *Tropidoleptus carinatus* (Conrad).

The crescent-shaped pattern of outcrop of the Dundee and younger formations is indicated in figure 2. The width of outcrop narrows abruptly northward in the vicinity of the Lucas County monocline where the beds have a steep westward dip. Further south the rocks dip gently northwestward into the Michigan basin.

As already mentioned, practically all exposures of the Dundee are limited to quarry excavations in Lucas County. Three quarries in the Silica region expose an almost complete section: the west quarry of the France Stone Company, and the south and north quarries of the Medusa Portland Cement Company. Other sections are exposed in abandoned quarries: a small quarry on the southeast edge of the village of Whitehouse, and a small quarry about 3 mi. southeast of Whitehouse, known locally as the Ryan quarry. (figure 2.)

In the Silica quarries a total thickness of 61 ft., 5 in. of Dundee limestone is recognized (Ehlers et al., 1951, p. 18). Of this 20 ft. constitutes the "upper" Columbus of Carman, and Bassett (1935). The rocks exhibit various blue, gray, and brown hues, and occur in beds of variable thickness. They are exceedingly fossiliferous, and the fossils together with the lithology are the bases used for

the subdivision of these upper beds into 5 zones (units 7–11 of Ehlers, etc.). A few of the several species in common with the Dundee in Michigan are: *Productella spinulicosta* Hall, *Brevispirifer lucasensis* (Stauffer), *Atrypa costata* Bassett, and *Paracyclas proavia* (Goldfuss).

The lower Columbus (Ehlers, 1951, p. 18,) (units 1–6) comprise approximately 41½ ft., the lower 8 ft. in large part a covered interval. Lithologically this division differs from the upper in that it is much more dolomitic, contains more chert, and is much less fossiliferous. Colors tend to be buff-gray rather than bluish-gray. The most fossiliferous layer is unit 4, exposed in a cut in the east wall of the west quarry of the France Stone Company. The nodular chert layers are especially rich in fossils. The ostracods described by Kesling (1954) came from this unit. Common Dundee species present are *Brevispirifer lucasensis* (Stauffer), *Glyptodesma erectum* (Conrad), *Atrypa elegans* Grabau, and *Tentaculites scalariformis* Hall.

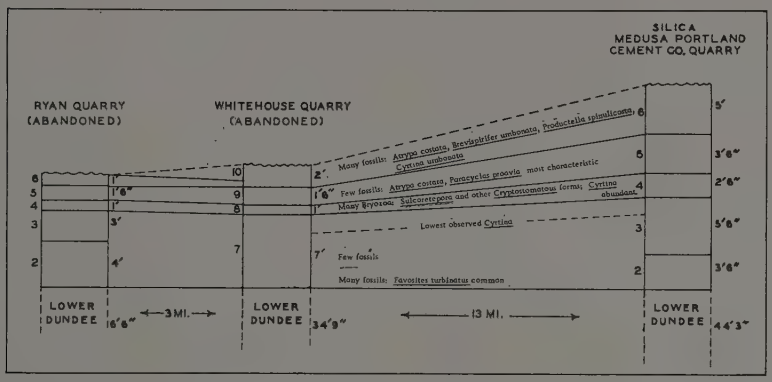

FIGURE 3. Zones of the upper Dundee limestone at Ryan, Whitehouse and Silica quarries. (After Carman, unpublished manuscript)

The three sections shown in figure 3 are sections of the upper Dundee ("Upper" Columbus) after Carman (unpublished manuscript). The zones at Silica, in the quarry of the Medusa Portland Cement Company are identical with those published in the field guide of Ehlers et al. The Whitehouse quarry section is thinner, 11½ ft., and the four zones recognized there may be correlated with the zones at Silica on the basis of fossils, zone 7 being the equivalent of zones 2 and 3 (7 and 8 of Ehlers). About 35 ft. of the lower Dundee are exposed, which are similar lithologically to the lower Dundee at Silica.

In the Ryan quarry, 10½ ft. of upper Dundee are exposed, which may be correlated with the 5 zones in the Medusa Portland Cement Company quarry. Only 6½ ft. of the lower Dundee are exposed here.

Since the concentration of fossils seems to be biocoenose in the various assemblages, highly fossiliferous layers alternate with layers having few or practically no fossils. Therefore in table 4 it will be noted the zones recorded for the different quarries are those which contain most of the fossils. An exception to this is zone 2 at Silica which is quite fossiliferous, but no species were collected from it that were not recognized in the other zones. One of the most striking features of brachiopod distribution is exemplified by the genus *Cyrtina* which is abundantly represented in all zones from its first appearance in the upper half of zone 3 to zone 6 at the top of the formation where it appears to have its greatest development.

FAUNAL CONTENT AND RELATIONSHIPS

Since the type region for the Middle Devonian limestones in Ohio is in the central part of the state, an understanding of their fossil content is a matter of first consideration, because correlation with Middle Devonian rocks elsewhere, particularly in the New York and Applachian regions was made here first primarily on fossils. Where the diastemic contact between the Columbus and Delaware limestones is not recognizable, and where the bone bed layer at the top of the Columbus is poorly developed or missing, fossils are the only reliable means of separating the two formations.

Fauna of the Columbus Limestone

The Columbus limestone is an abundantly fossiliferous formation particularly in the upper half. The fossils are very commonly preserved as casts, external molds, and steinkerns. In many of the chert layers, however, particularly in zone D, the delicate external markins of the shells are beautifully preserved. The invertebrate fauna is typically marine but the vertebrate fauna has remains of fresh water fishes. Remains of these fishes, in the form of teeth, dermal plates, and spines, are particularly abundant in the bone bed layer at the top of the formation. Likewise the remains of fresh water plants, ancient trochiliscids, are represented by spores which are present in abundance in certain layers. These are identified as *Eutrochiliscus devonicus* (Willard) by Raymond E. Peck (personal communication).

The fossils are not distributed uniformly throughout the formation. Some beds, particularly zone A (conglomerate) and a large portion of zone B, are sparingly fossiliferous, while in others, such as zones C and F, fossils are so abundant as to constitute distinct biozonal faunules. Certain species are long ranging forms such as *Favosites turbinatus* Billings, *Sulcoretepora gilberti* (Meek), *Atrypa "reticularis"* (Linnaeus), *Productella spinulicosta* Hall, and *Tentaculites scalariformis* Hall. Others are restricted stratigraphically and are excellent guide fossils for this age rocks: *Paraspirifer acuminatus* (Conrad), *Brevispirifer gregarius* (Clapp), and *Nucleocrinus verneuili* (Troost). Numerous gastropod species are found only in the chert zone (D).

In the progress of time, evolutionary changes must have taken place in the indigenous faunas, but migratory elements too probably played a very important part in producing the highly diversified elements of the Columbus limestone fauna. Many believe these faunal migrations came from two sources: a southern source where related forms are found in older Devonian beds in South America, and a northern source having elements related to north and north-central Europe. However, in view of the fact that the Columbus limestone thins northward with only the upper beds extending to the northern-most limit near Ingersoll, Ontario, it is questionable whether a sea ever did extend into Ohio from the north at this time.

The nearest correlative of the Columbus limestone fauna eastward in the Appalachian region of New York is not certainly known. Although long considered a typical Onondaga fauna, it probably approximates in age only the upper part of it. In the Beachville-Ingersoll area in Ontario about 40 mi. north of Lake Erie, the Columbus limestone overlies the Detroit River group, whereas a few miles to the northeast the Onondaga occurs below the Detroit River group. (Caley 1947, p. 1, 170). The Columbus limestone, therefore, is stratigraphically younger than the Onondaga limestone in that region.

As already stated the Columbus fauna is dominantly one of marine invertebrates. By far the greatest percentage of species is made up of brachiopods, gastropods, corals, pelecypods, cephalopods, and bryozoa, in that order of importance, with trilobites, echinoderms, and stromatoporoids comprising a much smaller element.

In more recent years, a number of species of foraminifera (Stewart and Lampe, 1947), and of ostracodes (Stewart, 1950) have been added to the list. Conodonts have been recovered in considerable abundance from the bone bed layers, and a study of them is now underway by the writer.

Corals.—The Columbus limestone is amazingly rich in corals, in dolomitic as well as in the purer calcium carbonate phases of the formation. The best known and probably greatest concentration is in the coral biostrome (zone C), but locally smaller assemblages of the reef type occur at several different horizons. The smaller individual cup corals, i.e., *Zaphrentis phrygia* and *Cystiphylloides vesiculosum* are found scattered from zone C up through zone H. In the upper 3 or 4 ft. of zone H these two species may be found in abundance along exposed and weathered joint surfaces where the exposed part is always silicified.

The coral biostrome (zone C) is made up of many different species of the family Favositidae, sprawling, branching types, such as *Favosites limitaris*, *Emmonsai carmani*, and many species of *Cladopora*. Larger, headlike masses are also represented, particularly such species as *Favosites goldfussi*, *F. turbinatus*, and *Emmonsi emmonsi*. Long cylindrical specimens of the tetracoral *Heliophyllum halli* are particularly striking in the quarry exposure on the south edge of the town of Dublin in Franklin County. Stromatoporoids make up a large portion of the biostrome here of which *Clathrodictyum ponderosa* appears to be the most common, if not the only species. The largest of all the solitary tetracorals *Siphonophrentis gigantea* (Lesueur) is found in all zones above A.

Of the smaller biostrome assemblages, one occurs locally in zone H, about 4 ft. below the top of the Delhi member, made up almost entirely of *Eridophyllum seriale*. This species is recognized in many exposures along the Scioto valley and north to Ingersoll, Ontario, but not in the Bellefontaine outlier. Stratigraphically it appears to be restricted to the upper few feet of the Columbus formation.

The genus *Hexagonaria prisma* likewise forms a secondary biostromal layer in the upper part of zone H in central Ohio. The species is also recognized in the Bellefontaine outlier, in a 2-foot exposure of the Columbus limestone in the General Pratt quarry, near West Liberty. This suggests a stratigraphic position high up in the Columbus for the rock at this place.

And yet another small biostrome is developed by the coral *Emmonsia emmonsi* in the lower part of the Delhi (zone E), at the base of the falls in Hayden Run, which is tributary to the Scioto River. However this coral must have had its optimum development in lower Columbus time, since it forms such a large part of the coral zone (C), and later occurrences such as this are doubtless due to stragglers that were able to survive a changing environment without significant change in fundamental specific features.

About a mile southwest of Cable in a small abandoned quarry, and along a small run which passes through it, 22 ft. of Columbus limestone are exposed (Stauffer 1909, p. 98). In chert layers in Bed 4 of this section occurs the species *Pleurodictyum* (*Procteria*) *michelinoidea* (Davis) [1] in sufficient abundance to form a secondary biostrome. This is the lower Columbus of Moses (1922, p. 57). The species identified by Stewart (1938, p. 65), as *Favosites pleurodictyoides* Nicholson from Erie and Sandusky counties is probably consepecific with it. Stumm (1950, p. 212) recognized the species in Erie County. So far as the writer knows these are the only reported occurrences of this coral in Ohio. On Kelly's Island in Erie County, the species occurs high up in the Columbus in association with *Paraspirifer acuminatus*.

Blastoids. Although only two species of blastoids have been recognized in the Columbus limestone, they are of distinct value because of their limited stratigraphic range in the formation. They are known only in zone H. in central Ohio,

[1] This is the *Pleurodictyum problematicum* Goldfuss of Stauffer, Stewart, and others.

and in the stratigraphic equivalent northward. The two species are: *Codaster pyramidatus* Shumard, and *Nucleocrinus verneuili* (Troost). *C. pyramidatus* is one of the more common species in the zone, and is frequently found in a silicified condition along weathered joint surfaces in the rock. To my knowledge the geographic distribution of this blastoid is limited to Franklin and Delaware counties. On the other hand *N. verneuili* is found distributed throughout the central belt to Lake Erie, and is such a distinctive and abundant fossil that Wells (1947, p. 121) designated zone H, the zone of *Nucleocrinus verneuili*. It is an excellent guide fossil for this stratigraphic unit in Franklin and southern Delaware counties. Outside of Ohio both species are known only in rocks of Onondaga age.

Crinoids. Although several species of crinoids belonging to the genera *Dolatocrinus* and *Megistocrinus* have been reported from the Columbus limestone by earlier workers in the State very little additional material has been found apart from crinoid stems and plates. The latter form crinoidal layers in many places and, it is probable that the break down of the crown was brought about by shifting currents and sediments. Crinoids cannot be considered as an important element in the Columbus fauna, and have not been helpful for stratigraphic and correlation purposes. In all 13 species have been reported, but careful collecting and study are necessary to establish their validity. Only fragmental plates and stems have been recognized in the Bellefontaine outlier.

Bryozoa. The presence of many bryozoa throughout the upper half of the Columbus formation indicates they must have formed populous communities in the middle Devonian seas. However, they are never assembled in large biozonal masses which suggests they never did assume too great importance as reef-building organisms. The cryptostomatous forms are by far the most prevalent, and are mostly represented by the lace-like fronds of the family Fenestrellinidae. These are especially noticeable in zone D, where they are commonly found enclosed in the chert layers. Other delicate branching forms, such as *Sulcoretopora gilberti* (Meek) are more common in zone C, although they are recognized in all the upper zones of the Columbus and into the Delaware limestone above. In general, the importance of the bryozoa diminished considerably with the oncoming of the more muddy seas of the Delaware.

Since the days of James Hall very little active research has been done on this important rock forming group of invertebrates in the middle Devonian limestones here. At least 25 species have been recorded from these rocks, but much detailed work is necessary in order to evaluate the validity of these species. Their use in the stratigraphy of the rocks and for correlation elsewhere has yet to be determined. It may be said, however, that the Columbus limestone species, at least, tie in fairly closely with the Onondaga forms of New York State.

Brachiopods. Hosts of brachiopods must have lived in the Columbus seas since their shells are preserved in such abundance and variety in the limestone. Their concentration in great numbers in certain layers has proved to be most helpful in the zonation of the formation. They are usually excellently preserved either by replacement, or by infiltration of mineral matter. Some specimens appear to have had very little change in shell substance. Brachiopods are present in all zones above A, and reach their maximum development in the more highly calcareous phase of the formation in zones E through H. More than 80 species have been reported, some of which occur in extreme abundance, while others are represented by only occasional specimens. The brachiopod fauna, probably more than any other group of invertebrates in the limestone has an undeniably Onondaga cast, but in addition certain Hamilton species suggest a possible later age than the New York and Ontario Onondaga. There is a remarkable similiarity in species throughout the whole of the central belt and the Bellefontaine outlier.

Probably the most important group is to be found in the *Spiriferacea*. Certain species have a limited stratigraphic range in the formation, and hence have proved

to be extremely useful as guide fossils for the zones. Swartz (1907, p. 64, 65) used them first in helping establish the upper boundary of the Columbus limestone in northcentral Ohio, and in correlating the rocks with the central area. Later Stauffer (1909), Ireland (1922), and Wells (1947) demonstrated additional stratigraphic values, and paleoecological factors relative to the ancient environment of these organisms.

Outstanding species of the spiriferids are *Paraspirifer acuminatus* (Conrad) and *"Spirifer" duodenarius* (Hall) of the upper Columbus, notably zone H; *Brevispirifer gregarius* (Clapp), especially common in zone F and not found above zone G; *"Spirifer" macrothyris* Hall of zone E; and *"Spirifer" varicosa* Hall, most abundant in zone D. These various species constitute the Spiriferid hemerae of Wells (1947, p. 121). Outside of Ohio they are especially characteristic of upper Onondaga (Onesquethaw) rocks, and are not recognized in younger formations.

Members of the superfamily Strophomenacea take second place in importance to the Spiriferacea in abundance of individuals and variety of species. Two of the most striking species because of their large size are common middle Devonian forms: *Megastrophia hemispherica* (Hall) and *Strophonella ampla* (Hall). The former occurs in all zones but A of the Columbus limestone and ranges up into the Delaware with no apparent change. The latter is confined to the Columbus, but is not so abundant northward as in the central region where it is especially characteristic of zone E, but occurs in the upper zones too. *S. ampla* is a widely distributed species in lower Onondaga rocks in other regions. The Ohio form may be different because it has a longer hinge than is typical elsewhere.

The identification in the Columbus limestone of two other species of the family, *Protoleptostrophia perplana* (Conrad) and *Stropheodonta demissa* (Conrad) is questionable, because outside of Ohio they have been recognized in rocks of Hamilton age only. In Ohio both species are known in rocks of comparable age: Delaware limestone, Olentangy and Silica formations. The Columbus limestone specimens are usually smaller and less robust, particularly *S. demissa*, than in the younger rocks.

The Middle Devonian aspect of the brachiopods is emphasized in the character and abundance of the atrypids. Most of them are identified, probably incorrectly, with two species: *"Atrypa reticularis"* (Wilckens) a catch-all species name for many unnamed Devonian species of *Atrypa*, and *A. "spinosa"* Hall, an upper Hamilton (Moscow) age form in New York State and associated areas. Mature specimens of the former species are large and robust, with finely plicate surface, and with an exceptionally convex brachial valve. The latter species is much smaller, both valves are somewhat flattish, and the plications are strong. It is extremely abundant in zone F, much more so in certain layers than the typical *Brevispirifer gregarius* of the zone. Some specimens with still heavier plications, and sometimes with shelly, spinose extensions may belong to yet another species.

The occurrence of the long-ranging *Leptaena "rhomboidalis"* Wilckens in the upper two zones of the limestone in relative abundance, particularly in zone H, as compared with its extreme profusion in the lower zones J and K of the Delaware above is noteworthy. The same stratigraphic positions are maintained in the northcentral area, but interestingly enough the species has not been found in the Bellefontaine outlier. The typical Columbus example is a large, robust individual, and should be restudied, and probably renamed.

At least nine species of the genus *Chonetes* have been reported from the Columbus limestone, but many of these identifications are questionable. One Middle Devonian species, *Chonetes mucronatus* Hall, is the species most commonly recognized in both limestones, ranging through several zones of each. It has been reported as a common brachiopod in zones C through H, but this abundance is not evident in casual collecting as it is with many other brachiopods. The whole group here needs restudy and revision.

Other distinctive brachiopods rather widely distributed but never abundant are: *Pholidostrophia nacrea* (Hall), *Productella spinulicosta* Hall, *Rhipidomella vanuxemi* Hall, and *Schizophoria propinque* Hall. These will be discussed in connection with the northwest section since they are of much more consequence in the faunas there than in the central area.

Pelecypods. Although 60 or more species of pelecypods have been reported from both Columbus and Delaware limestones, only 8 or 10 occur in abundance, and these more commonly in the shaly phases of the Delaware. However, more species are known from the Columbus, but generally they are scattered, and seldom constitute biozones of appreciable development. As a rule the shell features are not well preserved. The three most common species in the Columbus limestone are: *Conocardium cuneus* (Conrad), *Paracyclas proavia* (Goldfuss), and *Cornellites flabella* (Conrad).

Of the foregoing *C. cuneus*, suggested designation by Branson (1942, card 7) *C. cuneus cuneus* to separate it from associated varieties, is certainly the most distinctive if not the most abundant of the three. It was first recognized by Hall (1885, p. 410) in the limestones in Franklin County, and since then has been reported from almost every outcrop of the Columbus limestone throughout the whole of the central belt, and from the Delaware limestone in the northcentral area. The species is especially abundant in zone C of the former formation, and in zone D associated species are: *Conocardium cuneus attenuatum* (Conrad), *C. cuneus subtrigonale* d'Orbigny, and *C. ohioense* Meek. *C. cuneus* is the most commonly recognized species of the genus in eastern Devonian faunas, ranging from Oriskany through Hamilton.

Paracyclas proavia (Goldfuss)[2] (the *P. elliptica* of most writers) likewise has been reported from nearly all exposures of the formation, and is one of the more common fossils in zones C-G. It extends into the Delaware above but is much more restricted within the formation. In contrast to *Conocardium cuneus*, which usually has the shell features preserved, *P. proavia* seldom has any shell retained, and internal molds or steinkerns are the usual mode of occurrence. The stratigraphic range of the species is Onondaga and Hamilton.

Two other species of *Paracyclas* of more local and less abundant occurrence in central Ohio are: *Paracyclas ohioense* Meek, in zones C and D of the Columbus limestone, and *P. lirata* (Conrad) in the Delaware limestone.

Cornellites flabella (Conrad), a rather widely distributed Middle Devonian pelecypod in New York and adjoining states, is most common in the shaly phases of the Hamilton, but in Ohio it is most common in the more highly calcareous phase of the Columbus, notably in zones E and G, and in the lower part of the Delaware, especially zone K. The species in the two formations may not be conspecific, since the specimens in the Columbus limestone are larger, and have coarser surface sculpture than in the Delaware. A Hamilton species of doubtful identification is *Modimorpha concentrica* (Conrad), which is found in considerable abundance from zones D through G, but is most common in zones E and F. It might be noted from the few foregoing species cited, that the Columbus limestone pelecypods show a close affinity to those in younger age rocks, more specifically, Hamilton.

Gastropods. Although gastropods form a rich and varied element in the Columbus limestone fauna they do not usually occur in such profusion as some other groups of fossils, such as corals and brachiopods. Their greatest concentration is to be found in the cherty layers of zone D (Eversole member) in the central area, near the base of the formation. This zone is commonly referred to as the gastropod zone. At least 60 species have been reported from this zone by various paleontologists, which is an amazingly large number, when all told only about 75 species have been recorded from the entire formation. Perhaps the more conserva-

[2]See LaRocque, 1950.

tive figure of 30 of Wells (1947, p. 122) is nearer the truth, and from my own observations even less than this. However, gastropods are found in more or less abundance in all zones in the limestone above the chert layer.

Gastropods in zone D are characteristically the smaller-shelled forms such as several species of bellerophontids, pleurotomarids, and high-spired turritellid forms, represented especially by the genera *Murchisonia* and *Loxonema*. The external shell features are generally remarkably well-preserved in the more chalky phases of the chert.

In the higher more calcareous rocks of the limestone the usual mode of preservation is in the form of internal molds or steinkerns, and in general the larger, thicker-shelled species are best represented.

Since earlier paleontologists and stratigraphers considered the Columbus limestone to be more or less the equivalent in age of the Onondaga of New York State and adjoining areas a large proportion of the fossils are identified with species of this age. Many of these species are based on Ohio material, the major contributions having been made by Whitfield, Newberry, James Hall, and Stauffer. A critical study of this whole important group is necessary in order to determine the validity of the many lower Onondaga species that have been identified in the Ohio rocks.

Although numerous gastropod species have been reported from the Columbus limestone, only a relatively few occur in any great abundance. In the local collecting areas in the quarries in Franklin and Delaware counties along the Scioto River the common and more abundant species in the chert zone D are: several species of the bellerophontids, *Bellerephon pelops* Hall being one of the more abundant ones, *Elasmonema bellatulum* (Hall) and *Elasmonema lichas* (Hall) which are probably synonymous species, *Isonema humile* Meek, *Mourlonia lucina* (Hall), *Pleuronotus decewi* Billings, one of the largest gastropods in the zone, and usually preserved as a steinkern; and *Loxonema pexatum* Hall, *Loxonema robustum* Hall, and *Murchisonia desiderata* Hall among the high-spired turritellid forms.

Higher up in the limestone, notably in zones E, F, and G, *Mourlonia lucina*, *Pleuronotus decewi*, *Loxonema pexatum*, and *Murchisonia desiderata* are the most abundant and conspicuous forms. In zone H, the spiny platycerids are the dominant type, *Platyceras* (*Platyceras*) *dumosum* Conrad, and *P.* (*Platyceras*) *carinatum* Hall being the more common forms. In the upper part of the zone, *Tentaculites scalariformis* Hall, which is widespread and extremely abundant in zone J of the Delaware limestone, occurs in relative abundance in certain layers in zone H, and is sparingly distributed down to zone D. This questionable pteropod has a stratigraphic distribution from Onondaga through Hamilton in the Appalachian states and west to Michigan.

All of the aforementioned species have been recognized in the Columbus limestone in Ohio northward to Lake Erie, and in the Bellefontaine outlier exposure, but nowhere approaching the abundance in the central area. The total gastropod species likewise falls far below that of the central region. The paucity of species can be readily understood with the realization that the lower Columbus of the central area (zones A to D) is missing from these regions, hence ruling out the rich concentration of species of the chert zone D.

Cephalopods. Although 40 or more species of cephalopods have been reported from the Columbus limestone by various workers, probably not more than half that number are commonly recognized. Of the 36 species listed by Stauffer (1909), 16 were not collected by him, but some of these are represented in the Geological Museum collections at The Ohio State University. Most of the collection in the museum was studied by Flower (1945), with the result that several described species were assigned to new genera, and some new ones recognized.

The cephalopod fauna is almost exclusively nautiloid. The shells and shell features are rarely preserved. Steinkern fillings are the common mode of preserva-

tion, and since the siphunclar features have either been destroyed or made indistinct in the process of fossilization, identification in many cases is difficult and uncertain.

Although cephalopods form an important element in the Columbus fauna they are not generally abundant as to individuals. The peak of development is in zones E and G, particularly in the latter zone which is commonly referred to as the "cephalopod zone." Specimens are rare in zone C, but in zones D and E straight orthoceracones and gently curved cyrtoceracones appear in fair abundance in species and individuals. *Michelinoceras ohioensis* (Hall) is the most commonly recognized of the straight forms. Several associated species originally referred to the genus *Orthoceras* are now known to belong in other genera, such as *Spyroceras*, but at the moment their correct specific category is not known.

The notable development of gyroceracones and exogastric brevicones is the outstanding feature of zones E and G. Occasional specimens of these groups are found at lower stratigraphic levels in the formation down to zone D, but the climax of their development is in the upper part of the formation. Because of the large size attained by many individual specimens they are unquestionably the most striking fossils in this part of the limestone. The large, loosely coiled, gyroconic types are best represented. Of these *Goldringia cyclops* (Hall) and *Wellsoceras columbiense* (Whitfield) are by far the most common species. An amazingly large size, up to a foot in length, is reached by some specimens of the exogastric brevicone *Acleistoceras eximium* (Hall).

North of Delaware County there is a striking decline in the cephalopod fauna, and specimens are few and identification very uncertain. Apart from one or two questionable specimens none at all have been collected from the Bellefontaine exposure.

The cephalopod fauna of the Columbus and adjoining areas is recognized as having its closest affiliations with that of the Schoharie grit and Onondaga limestone of New York, and the Jeffersonville limestone of Indiana. Most conspicuous genera common to these formations are *Goldringia*, *Wellsoceras*, and *Needyceras*, which seem to be best represented in the lower middle Devonian of these areas.

Trilobites. Trilobites form an interesting if not a prolific portion of the Columbus limestone fauna. They are distributed throughout the formation from zones C through H in the exposures around Columbus and adjoining areas where they are most common in the upper, more calcareous phase of the limestone, particularly in zones E and F. As is usual with this class of Crustacea the remains are fragmentary so that seldom is a specimen found in a complete state of preservation.

From all areas of exposure throughout the whole of the central outcropping belt and the Bellefontaine region 15 species have been reported. However 3 of these have a generally recognized stratigraphic position higher in the middle Devonian, typically Hamilton, and should be withdrawn from the list, restudied, and redefined. These are *Phacops rana* (Green), *Dechenella* (*Basidechenella*) *rowi* (Green), and *D.* (*Dechenella*) *planimarginata* (Meek). Specimens of *D.* (*Basidechenella*) *rowi?* are found more frequently than any other trilobite in the Columbus area, particularly in zone F of the limestone. The species does not fit into any of the Proetidae of Stumm (1953). Because of the smaller and less convex pygidium, and certain cephalic differences, the specimens can be readily distinguished from the associated *Proetus* (*Crassiproetus*) *crassimarginatus* (Hall).

The trilobite fauna is dominated by the families Phacopidae and Proetidae, and is unquestionably lower Middle Devonian (Ulsterian) in its content. The most outstanding species in the central area is the large-tailed *Coronura aspectens* (Conrad) of the latter family, but parts other than the pygidium are seldom found. The genus *Odontocephalus* is represented by 2 species, one of which, *O. aegeria* Hall has not been recognized outside of the Bellefontaine outlier. *Phacops cristata* Hall of the Phacopidae is probably the most abundant of the trilobites in the Columbus district.

Ostracods. Only a few fragments of ostracods have been recovered from the limestone. The study by Stewart (1950) on Ostracoda of the Middle Devonian Bone Beds in Central Ohio showed their occurrence to be mainly in Bone Bed 3 of the Delaware limestone. Additional study is necessary to determine their almost certain presence in other parts of the formation.

Vertebrate Remains. Vertebrate remains are represented mostly by fish remains and conodonts. The outstanding contribution on fishes was made in the several reports of John S. Newberry, and in the more recent report of Wells (1944) on the microscopic fish remains from the bone beds of the Cincinnati arch region. Fish remains in both Columbus and Delaware formations are important and varified, and represent both fresh and marine water types.

Conodonts appear to be concentrated in the bone bed layers, and are almost exclusively represented by the families Icriodidae and Polygnathidae. Publication on this interesting, but debatable group of microfossils is still to be made.

Fauna of the Delaware Limestone

The wealth of fossils in the upper two-thirds of the Columbus limestone gives way to a much more restricted and conservative assemblage in the Delaware limestone. The change in lithology from a highly calcareous limestone to scattered beds of shale, particularly in the lower part, and to dark unfossiliferous chert and rather massive, blue to brown limestone further up evidently represents an environment not nearly so favorable for living organisms as the clear seas of earlier times. There were probably many factors which contributed to the reduction of the highly populous community of late Columbus time.

However, the fauna of the Delaware limestone is by no means meagre, although large parts of it have few or no fossils. Over a hundred species have been reported from it, which is less than a third of the number in the Columbus limestone below. As a rule the fossils are not scattered through the formation to the same extent, and are more likely to be found concentrated to form highly fossiliferous layers. Few species but abundant individuals seem to have been the rule in these ancient colonies. A good example of prolifity in individuals is demonstrated in zone J where innumerable individuals of the pteropod *Tentaculties scalariformis* are interspersed with relatively few specimens of other species. Likewise zone K offers another notable instance where some rock layers are literally paved with finely preserved specimens of *Leptaena rhomboidalis* to the exclusion of all but a few other fossils, mainly brachipods, and the distinctive pelecypod *Grammysia bisculata.* These striking accumulations of so many individuals in restricted stratigraphic zones are valuable aids in the zonation of the formations.

The Delaware formation begins with a 6-foot layer of shale interbedded with black chert and thin limestone layers which is characterized faunally by the inarticulate brachiopods *Lingula manni* Hall and *Orbiculoidea lodiensis* (Vanuxem), and the articulate form *Leiorchynchus limitare* (Vanuxem). *Lingula manni* is not so common as the other two species in the Columbus district, but further north in southern Delaware County it appears in greater abundance and higher up in the formation. It was the recognition of these typically Marcellus species of New York State that lead Whitfield to confirm Winchell's earlier opinion of the Hamilton age of the Delaware limestone.

In general the mode of preservation of the fossils is much the same as in the Columbus limestone, although it does seem that more specimens have the shell and shell features better preserved. This is particularly true of many brachiopods, such as *Leptaena.*

The general content of the fauna is in striking contrast to the lower formation. Gone are the the hosts of reef-forming corals although a few of the more hardy, adaptible species survive. Lingering colonies of the long ranging Favositidae occur here and there, such as *Emmonsia emmonsi* (Rominger), and *Favosites*

"*turbinatus*" Billings. Dominant tetracorals of the earlier sea are represented by only scattered specimens of former ubiquitous species, as *Cystiphylloides vesiculosum* (Goldfuss), and *Heliophyllum halli* Edwards and Haime. The spot light of the coral population rests in the little button-shaped *Hadrophyllum d'orbigni* Edwards and Haime, which by all odds is the most abundant and distinctive coral in the formation. The species is not restricted to the Delaware limestone, but is also represented in zone H of the Columbus limestone. Its peak of development, however, is in zone L of the Delaware which is commonly spoken of as the *Hadrophyllum d'orbigni* zone because of the great profusion of this coral species here. This zone is also Bone Bed 3 of the Middle Devonian limestone series, a thanatocoenose assembly of mostly microscopic organisms such as small teeth, plates, and spines of fresh water fishes, marine ostracodes and conodonts, and plant spores. It is believed this little coral flourished in the sandy bottom close to shore rather than in the calcareous oozes of the deeper water.

Gone too is most of the rich stromatoporoid fauna of Columbus times. This is to be expected because stromatoporoids occur most commonly in association with coral reefs, and next to corals are probably the most important reef-forming organisms in the clear seas of the Silurian and Devonian periods. Their association with corals is best exemplified in the Columbus area in zone C of the Columbus limestone where large masses of rock are almost completely made up of them.

Of other clear-water sedentary invertebrates, such as blastoids and crinoids, apparently few had the fortitude to survive the turbid, stale environment of the Delaware seas. There is no evidence of the blastoid *Nucleocrinus verneuili* which survived to the very end of Columbus time, and which serves as an excellent index marker for zone H of the uppermost Columbus. Although a couple of species of the crinoid *Dolatocrinus* have been reported from the Delaware, crinoidal remains are commonly found only as frgamental plates and stems, concentrated in thin layers, particularly in the bone bed assemblages.

Of the Mollusca, gastropods and cephalopods are notably diminished from the Columbus. The gastropod population is decreased in species to possibly only one-sixth of the rich representation in the lower, calcareous limestone. Of those remaining the most common are the spiny Platycerids, which evidently accustomed themselves best to the changed environment. Some of the upper Columbus species still persisting into this higher horizon are *Platyceras* (*Platyceras*) *carinatum* Hall, *P.* (*Platyceras*) *dumosum* Conrad, and *P.* (*Platyceras*) *erectum* (Hall). The association of the Platycerids with crinoidal remains is found in restricted instances (Wells, 1947, 1. 120), but not to the extent of their development in the upper part of the Columbus.

The almost complete disappearance of the great exogastric brevicones of the lower limestone, and of most of the gyroceracones marks another significant change in the fauna. Of the latter, *Neadyceras contractum* Flower, and *Nassausoceras? ohioensis* Flower, are almost the sole representatives of this fast dwindling race. The Orthoceracones likewise have been reduced to a mere remnant of their former importance, and occasional specimens of *Michelinoceras? eriense* (Hall), and *M. ? ohioense* (Hall) are the most likely ones to be found.

Trilobites too have made a rapid exit from the scene, and careful collecting is rewarded usually by only an occasional example. In the general Sandusky area the two most common trilobites have commonly been identified with *Phacops rana* (Green), and *Proetus rowi* (Green). More recently Stumm (1953, p. 13) has recognized two species of the family Proetidae in northcentral Ohio: *Dechenella* (*Basidechenella*) *eriensis* Stumm, and *D.* (*Basidechenella*) *rowi sanduskiensis* Stumm. This latter subspecies name doubtless should replace the earlier, more casual identification with *Proetus rowi* of the Marcellus shale of New York. Whether this holds true in central Ohio, where only occasional poorly preserved and mostly unidentifiable fragmentary proetic material has been seen, is not definitely known

at present. *Phacops rana* is a common Hamilton species in the eastern and central states.

A glance at a list of Delaware limestone species shows the fauna to be dominantly one of brachiopods, with pelecypods following next in point of species. The two groups together comprise more than half of the macrofossil invertebrates reported from the formation. Between 50 and 60 species of brachiopods have been recognized, and about 20 species of pelecypods. The brachiopod fauna then is of first consequence in the fossil picture of the formation.

One of the outstanding aspects of the brachiopods is their concentration in layers, usually a great abundance of individuals for any given species. In all zones of the formation they are the most abundant fossils in point of species. Much of the fauna is reminiscent of the Columbus below, and many species have persisted into this higher horizon with little or no change. Some examples of these long-ranging forms are: *Atrypa "reticularis"* (Linnaeus), *Chonetes mucronatus* Hall, *Leptaena rhomboidalis* (Wilckens), *Pholidostrophia iowaensis* (Owen), *Productella spinulicosta* Hall, and certain of the *Stropheodonidae* such as *Stropheodonta demissa* (Conrad), *Protoleptostrophia perplana* (Conrad), and *Megastrophia hemispherica* (Hall).

However the decline in the spiriferids is notable, particularly those of recognized Onondaga age. Few of the Columbus types persist and the absence of striking species such as *Paraspirifer acuminatus* (Conrad), and *Brevispirifer gregarius* (Clapp) is one of the significant changes. Many new forms appear having a Hamilton cast. Some of these are *Mucrospirifer consobrinus* (d'Orbigny), *M. mucronatus* (Conrad), *Brachyspirifer audaculus* (Conrad), *Brevispirifer lucasensis* (Stauffer), and *Cyrtina hamiltonensis* (Hall). *M. consobrinus* is probably the most abundant of these species in the exposures around Columbus. *Brevispirifer lucasensis* has been recognized only in the northern part of the central belt.

Other brachiopod species of Hamilton age are: *Ambocoelia umbonata* (Conrad), *Chonetes coronatus* (Conrad), and *C. scitulus* Hall.

Pelecypods, like brachiopods, seem to have flourished in the advancing Delaware seas. A few of the species indigenous to the Columbus limestone still persist, but the appearance of new migrant types heralds the arrival and development of a new generation of species common to rocks of Hamilton age almost everywhere in the eastern and east-central states. Among the more common and characteristic Columbus forms that still remain but with sparse representation are: *Concardium cuneus* (Conrad) and *Paracyclas proavia* (Goldfuss). Hamilton age forms are recognized in such species as: *Pterinopecten (Pseudaviculopecten) princeps* (Conrad), *Glyptodesma erectum* (Conrad), *Grammysia bisulcata* (Conrad), *Paracyclas lirata* (Conrad), *Sphenotus cuneatus* (Conrad), and *Cypricardella tenuistriata* (Hall). The concentration of many individuals of *Grammysia bisculata* in zone K was remarked upon by Stauffer (1909, p. 30) and prompted Wells (1947, p. 121) to define it as the "zone of *Grammysia bisulcata.*"

Throughout the whole of the central belt of the Delaware formation in Ohio there seems to be a similarity in the distribution of pelecypod species. The species best represented appear to be *Glyptodesma erectum* and *Grammysia bisulcata*, particularly in the central region. They have never been found in the Bellefontaine outlier where the Delaware is believed to be absent.

In addition to the foregoing fossils, as previously mentioned, zone L (Bone Bed 3) has a wealth of microscopic fossils throughout the central region where it is exposed. A large fish fauna of 25 species was described by Wells (1944). Before this at least 15 species of fish had been described from the entire formation by Newberry and others. More recent studies by Stewart (1950) has revealed the presence of approximately 20 species of ostracodes in this bone bed which seem to have their closest affiliation with faunas of the Jeffersonville limestone of Kentucky, and with formations of Hamilton age at other localities. A considerable

conodont fauna has also been recovered which is represented almost exclusively by the Icriodids and Polygnathids, and which bears a surprising resemblance to the conodont fauna in the Olentangy shale above.

Fauna of the Dundee ("Columbus") Limestone

At first glance a list of fossil species from the Dundee ("Columbus") limestone of northwestern Ohio suggests a close resemblance to those of the Columbus limestone of the central area (table 4). Stauffer (1909, p. 182) remarked "The fauna of the Columbus limestone is essentially the same as in central Ohio. Only one, and possibly two species were obtained in the northwestern region which were not found to the east of the anticline." The writer, however, has not found such striking similarity in the faunas in the two areas. It is true that there are a considerable number of species in common, but many of these are forms that range through rocks of Onondaga and Hamilton age in New York State and other eastern areas.

Most of the fossils in the Dundee are to be found in the upper, more calcareous half of the formation. Certain layers are very fossiliferous, and these together with the changing lithology are very useful in zonation of the rocks. The lower half of the limestone, about 30 ft., is much more dolomitic in character, and fossil zones are much more infrequent. The only one of much consequence is a 1′ 3″ cherty, dolomitic limestone layer. The chert nodules in the limestone are quite fossiliferous, and contain a brachiopod fauna, some species of which have not been recognized in the formation before. The pteropod, *Tentaculities scalariformis* is especially abundant, and there are many ostracods described recently by Kesling (1954).

The accompanying list of fossils from the Dundee limestone (table 4) shows 103 species reported by various workers. However, only 60 which can be identified with reasonable accuracy, have been recognized in the collections which have formed the basis for this study. This includes the ostracods of Kesling which the writer has not examined personally, but has recognized as being present in the chert layers.

It will be noted immediately that this list falls far below the number of species reported from the Columbus limestone throughout the whole of the central belt. This may be explained partly by the fact that there are few natural outcrops in the northwestern area, and rock exposures of any extent are restricted to quarry excavations which are fewer than east of the anticline. But more important still the rich coral fauna of zone C and the highly diversified gastropod fauna of zone D, have no counterpart in the Dundee faunas. In addition the formation is at least 25 ft. thinner than the Columbus limestone.

As is true of the Columbus limestone the predominance of brachiopods species is the most notable feature of the Dundee. This is by no means true in abundance of individuals though, and in many instances a few meagre specimens seem to be the rule rather than the exception, whereas the same species in the central belt may be represented in most occurrences by a wealth of individuals. Forty-six species are included in the list presented here, 20 of which were reported by Stauffer and others, but were not collected or seen during the course of this study. Part of this discrepancy lies in the fact that the boundary between the Traverse and the Dundee as established by Stauffer is not generally accepted now, and the lower 4½ ft. of his Traverse at Whitehouse is included now in the upper Dundee as well as the equivalent 12 ft. now exposed in the Silica quarries. Therefore certain species such as *Cyrtina alpenensis* Hall and *Cyrtina hamiltonensis* (Hall) reported by him from these layers as Traverse, are recognized now as Dundee. The former species is common in the Traverse formation of Michigan, but only a few specimens of evidently identical specific features have been recognized in zones 7 and 10 of the Whitehouse quarries. A great abundance of *Cyrtinas* are

concentrated in zone 8 at the Whitehouse quarries, but these are believed to be more nearly related to *Cyrtina umbonata* (Hall) and are so regarded in this report. This species is believed to have a middle Devonian distribution.

There is no comparable development of *Cyrtinas* in the Columbus limestone east of the anticline. *Crytina hamiltonenesis* has been reported from both the Columbus and the Delaware limestones, but it is questionable whether the species in the two formations are identical. It is of frequent occurrence in zones G and H of the Columbus limestone, but never abundant.

On the other hand *Chonetes coronatus* Conrad, a typical widespread Hamilton species was reported by Stauffer from the Traverse only, but is recognized in this paper as extending down into the upper Dundee, but sparingly so. The great development of this species is in the Blue limestone of the Silica formation, the lower part of which is usually spoken of as the *Chonetes* zone. It is recognized also in the Delaware and Olentangy formations of central Ohio, but only by occasional specimens.

The atrypids are represented by species typical of the Dundee further north. *Atrypa costata* Bassett, which is more or less common throughout all the Upper Dundee, has been recognized in all the quarry outcrops of the present report, and *Atrypa elegans* Grabau in the upper part of the lower Dundee (zone 3 of Ehlers et al., 1951). It is probable that most of the specimens referred to *A. spinosa* Hall by Stauffer and others are more correctly identified with the first named species. *Atrypa elegans* has also been reported from the Delaware of Central Ohio although the writer has not collected any specimens of this species, nor has she seen any that might be referred to it. *Atrypa "reticularis"* (Linnaeus) previously reported from both Dundee and lower Traverse may include more than one unnamed species. Some specimens from zone 10, of the Whitehouse quarry probably represent still another undescribed form. They are closest to *A. spinosa* but have finer plications and more pronounced shoulders.

The Spiriferid population of the Dundee limestone is a mere shadow of the wealth of species and individuals in the Columbus limestone. The typical upper Onondaga *Paraspirifer acuminatus* so common in zone H, has not been recognized in the present study although Stauffer (1909, p. 148, 1551) reported it from the Dundee limestone along Tenmile Creek, and at Silica. Another typical Columbus species of zone H that is missing is *Spirifer duodenarius* (Hall). *Brevispirifer gregarius* (Clapp) is questionably present. It has been succeeded by a closely related species *Brevispirifer lucasensis* (Stauffer), found also in the Dundee of Michigan, and the Delaware limestone of central and northcentral Ohio. This is undoubtedly the most characteristic of the Dundee spirifers. *Brachyspirifer audaculus* (Conrad) a Hamilton species, is questionably identified by two or three incomplete specimens. It is recognized in the Delaware limestone of the central district.

The prevalence of *Pholidstrophia nacrea* (Hall) is notable, particularly in the Silica and Whitehouse outcrops, but specimens are not too numerous. Specimens from both Columbus and Delaware limestones in central Ohio are certainly similar, and there seems to be no valid reason not to identify them with this Hamilton species.

Productella spinulicosta Hall, has a similar stratigraphic and areal distribution, as *Pholidstrophia nacrea*, but is present in much greater abundance in the Dundee limestone. It is especially common in zones 4 and 6 at the Silica quarry, where the former zone is commonly referred to as the *Productella* zone. In the correlative zones 8 and 10 at Whitehouse, abundance of individuals is not so pronounced. Ehlers et al (1951, p. 17) notes that this species is the most characteristic fossil of the uppermost unit in the Silica quarries. It is likewise well represented in the Dundee of Michigan. *Productella spinulicosta* is regarded as a Hamilton species, although certainly I can find no appreciable difference between the Dundee form

TABLE 4

Dundee ("Columbus Limestone") fossils of northwestern Ohio and their distribution elsewhere in the state

Total list of species reported from Northwestern Ohio	Species from northwestern Ohio recognized in this report								Species reported by Stauffer (1909)	Species in Dundee of Michigan	N. Central and Central Ohio		Bellefontaine Outlier Columbus limestone
	Silica		Whitehouse			Ryan		Total			Columbus limestone	Delaware limestone	
	4	6	7	8	10	3	4, 6						
PLANTS													
Eutrochiliscus devonicus (Wieland)		X					X	X	X		X		X
STROMATOPOROIDEA													
Clathrodictyon ponderosum (Nicholson)	X				X			X	X		X		X
Clathrodictyon undulatum Parks		X						X					
Syringostroma densa Nicholson						X		X	X		X		
ANTHOZOA													
Bethanyphyllum sp.						X	X	X					
Coenites roemeri (Billings)					X			X			X		
Coenites tela (Davis)									X		X		
Cystiphylloides "americanus" (Edwards and Haime)	X					X		X			X		
Emmonsia emmonsi (Rominger)									X		X	?	X
Favosites polymorphus Goldfuss									X				
Favosites "turbinatus" Billings	X		X		X	X	X	X	X	X	X	X	X
Heliophyllum halli Edwards and Haime			X				X	X			X	X	
Heterophrentis prolifica (Billings)					X					X	X		
Hexagonaria anna (Whitfield)			X					X		X			X
Hexagonaria prisma (Lang and Smith)									X		X		
Hexagonaria tabulata Stumm					X		X	X		X			
Siphonophrentis gigantea (Rafinesque)			X[5]					X	?				
Zaphrentis phyrgia Rafinesque and Clifford	X	X	X[5]		X	X		X	X		X		X
Zaphrentis spp.									X				
CRINOIDEA													
Dolatocrinus sp.		X						X	X		X	X	
Crinoid fragments	X	X		X	X			X	X		X	X	X
BLASTOIDEA													
Nucleocrinus verneuili (Troost)									X		X		
BRYOZOA													
Fenestrellina spp.			X	X			X	X	X		X	X	
Monotrypa tenuis (Hall)									X		X		
Monotrypa sp.	X	X		X		X		X	X		X	X	
Paleschara sp.	X	X	X	X				X					
Sulcoretepora gilberti (Meek)	X	X	X	X				X	X	X	X	X	X
BRACHIOPODA													
Amphigenia elongata (Vanuxem)									X		X		X
Athyris vittata Hall				X				X					
Athyris vittata indianensis Stauffer									X		X		
Atrypa costata Bassett	X	X	X	X	X	X	X	X	X	X		X	
*Atrypa elegans grabau										X			
Atrypa "reticularis" (Linnaeus)									X		X	X	X
Atrypa sp. (undet.)					X	X	X	X					
Brachyspirifer audaculus (Conrad)		X						X				X	
Brachyspirifer manni (Hall)	X		X	X				X	X	X	X		
Brevispirifer gregarius (Clapp)				X				X	X		X		X
Brevispirifer lucasensis (Stauffer)	X		X	X				X		X		X	
Camarotoechia billingsi Hall									X		X	X	
Camarotoechia sp.							X	X					
Chonetes arcuatus Hall									X		X		
Chonetes coronatus Conrad			X		?			X				X	X
Chonetes hemisphericus Hall									X		X		
Chonetes mucronatus (Hall)				?		?		?	X		X	X	X
Chonetes scitulus Hall									X			X	
Chonetes sp.									X				
Cryptonella lens Hall									X		X		
Cyrtina alpenensis Hall									X				
Cyrtina hamiltonensis (Hall)									X		X	X	X
Cyrtina umbonata (Hall)	X	X		X	X	X	X	X					
Cyrtospirifer ? grieri (Hall)		X						X	?	aff.	X		
Douvillina inaequistriata (Conrad)	X							X					
Eunella linckleni Hall									X		X	X	X
Megastrophia hemispherica (Hall)	X	X	X	X	X			X	X	aff.	X		X
Megastrophia inequiradiata (Hall)			X	X	X			X	X		X		X
Mucrospirifer varicosus (Hall)	X								X		X		
Mucrospirifer n. sp.					X	X		X					
Nucleospira concinna Hall						X		X	X		X		
Orthothetis pandora (Billings)									X		X	X	X
Paraspirifer acuminatus (Conrad)									X		X		
Pentamerella arata (Conrad)									X		X		X

TABLE 4—(Continued)

Total list of species reported from Northwestern Ohio	Species from northwestern Ohio recognized in this report								Species reported by Stauffer (1909)	Species in Dundee of Michigan	N. Central and Central Ohio		
	Silica		Whitehouse			Ryan		Total			Columbus limestone	Delaware limestone	Bellefontaine Outlier Columbus limestone
	4	6	7	8	10	3	4, 6						
BRACHIOPODA (continued)													
Pholidops patina Hall and Clark									X		X		
Pholidostrophia nacrea (Hall)	X	X	X	X		X		X	X	X	X	X	X
Productella spinulicosta Hall	X	X	X	X		X	X	X	X	X	X	X	
Protoleptostrophia perplana. (Conrad)		X	X					X	X	X	X	X	X
Rhipidomella cyclas Hall									X				
Rhipidomella vanuxemi Hall		X						X	X		X	X	X
Rhipidomella variabilis Grabau	X							X		X			
Schizophoria foleyi Bassett	X							X		X			
Schizophoria propinque Hall									X		X		
Schuchertella n. sp.					X			X					
Spinocyrtia granulosa (Conrad)							?	?					
"Spirifer" segmentum Hall									X		X		
"Spirifer sp."							X	X	X				X
Stropheodonta demissa (Conrad)	?							?	X	aff.	X	X	X
Stropheodonta sp. (probably n. sp.)	X	X						X	X				
Strophonella ampla Hall							?	?	X		X		X
PELECYPODA													
Actinodesna occidentale (Hall)	X		X					X	X	X	X		X
Actinopteria boydi (Conrad)									X		X		X
Aviculopecten sp.									X				
Conocardium cuneus (Conrad)	X	X	X	X	X			X	X		X		X
Conocardium subtrigonale d'Orbigny	X	X						X		X	X		
Cornellites flabella (Conrad)					X			X	X	X	X		
Limoptera macroptera (Conrad)		X						X			X		
Limoptera pauperata Hall									X				
Modiomorpha concentrica (Conrad)									X		X		X
Panenka alternata Hall									X		X		
Paracydas proavia (Goldfuss)	X	X	X	X	X	X		X	X	X	X	X	
Schizodus sp.									X				
GASTROPODA													
Bellerephon pelops Hall	?							?			X	?	X
Elasmonema bellatulum (Hall)		X						X			X		X
Elasmonema lichas (Hall)					X			X	X		X		X
Isonema humile Meek	?							?	X		X		
Loxonema robustum Hall									?		X		
Mourlonia arata (Hall)									X				
Mourlonia lucina (Hall)			X	X				X	X		X		X
Murchisonia desiderate Hall									X		X		X
Murchisonia sp.									X				
Platyceras (Platyceras) carinatum Hall									X	X	X	X	
Platyceras (Platyceras) dumosum Hall	X							X	X	X	X	X	X
Platyceras (Platyceras) keoughi Bassett		X						X		X			
Platyceras sp.									X				
Pleuronotus decewi (Billings)	X			X	X			X	X	X	X		X
Trochonema meekanum Miller									X		X		X
PTEROPODA													
Coleolus tenuicinctus (Hall)	?							?	X	cf.			X
Tentaculites scalariformis Hall	X							X	X	X	X	X	X
CEPHALOPODA													
Acleistoceras eximium (Hall)	?	X						X			X		
Michelinoceras eriense (Hall)					X			X				X	
Michelinoceras ohioensis (Hall)		X						X	X	X	X		
OSTRACODA*													
Barychilina periptyches Kesling	X							X					
Dizygopleura compsa Kesling	X							X					
Endolophia chariessa Kesling	X							X					
Hollinella variopapillata Kesling	X							X					
Octonaria sp.	X							X					
Trypetera barathrota Kesling	X							X					
TRILOBITA													
Coronura sp.						X		X					
Dechenella (Dechenella) planimarginata (Meek)	X	X	X					X	X	X			
Dechenella (Basidechenella) rowi (Green)									X		X	X	X
Phacops cristata Hall			X					X	X		X		X
Proetus (Crassiproetus) crassimarginatus Hall								X	X		X		X
PISCES													
Dipterus castmani Stauffer						X		X	X				

*In lower Dundee (Zone 3 of Ehlers) at Silica. †Zone 4 of Kesling (1954).

and those that we commonly identify with the species in the Columbus limestone. Biozonal development however is not apparent in the latter formation, and specimens are found scattered through it and in the Delaware above.

Of the Strophomenacea there is a notable decrease of several species which are remarkably well developed in the central belt. Of particular note are the large and distinctive forms of *Megastrophia hemispherica* (Hall), and *Strophonella ampla* Hall. Specimens from the Dundee limestone studied by the writer are only questionably referred to these species, and for more accurate determination more and better preserved material is necessary. The genus *Megastrophia* appears in much greater abundance in the basal blue limestone of the Silica formation above, as well as associated species of *Protoleptostrophia* which are very common.

As compared with Central Ohio one of the most striking omissions from this northwestern fauna is *Leptaena rhomboidales* (Wilckens). Because of its wide range through Silurian and Devonian rocks the species is considered to have little stratigraphic value. But certainly its absence from rocks believed to be comparable in age to the Delaware of the central section where it is such an abundant species is surprising. Not even a straggler has been reported from the Dundee further north in Michigan.

Mollusca are represented by gastropods (including pteropods), pelecypods, and cephalopods, in that order of abundance as to species, and next to brachiopods probably make up the largest bulk of the fauna. Again, however, there is nothing even approaching the notable development of this phylum in the central area, and identifications are based for the most part on fragmentary and imperfect material. Identification of the few spiny platycerids that have been observed with *Platyceras* (*Platyceras*) *carinatum* Hall, *P.* (*Platyceras*) *dumosum* Hall, and *P.* (*Platyceras*) *keoughi* Bassett, are believed to be reasonably correct. The first two species are common Columbus limestone forms, and all three are recognized in the Dundee of Michigan. *Mourlonia lucina* (Hall), and *Pleuronotus decewi* (Billings) have been identified, not too confidently, from a few steinkern fillings which show nothing of the external features. Several specimens of *Elasmonema lichas* (Hall) from zone 10 of the Whitehouse quarry appear to be typical of the species. These gastropods apparently represent lingering elements of the flourishing hosts of the earlier Columbus seas.

The persistence of the pteropod *Tentaculites scalariformis* Hall and its relative abundance in the nodular chert layers of unit 4 (Ehlers, 1951) suggests the middle Devonian age of the Dundee. The specimens are a little more delicate in character than those of the Columbus and Delaware limestones, and have the surface features excellently preserved in the chalky matrix of the chert. Associated are some small specimens of what I believe to be *Coleolus tenuicinctus* (Hall), generally recognized as of Hamilton and upper Devonian age.

Only 6 Pelecypod species have been identified by me with a reasonable degree of assurance. Of these, two species which are most conspicuous in the Columbus limestone are also the most commonly occurring ones in the Dundee, but are not nearly so abundant: *Conocardium cuneus* is present in both the Silica and Whitehouse exposures, being most abundant in zone 7 at Whitehouse. Bassett (1935, p. 441) identified the species in these places as *C. subtrigonale* d'Obrigny, but it certainly appears identical with *C. cuneus* of the central Ohio area. Two or three small specimens from zone 4, Silica, are being referred doubtfully to *C. subtrigonale*. The presence of this species in the Dundee of Michigan is questioned by LaRocque (1950, p. 320) since it has been identified there only in drift material. *C. cuenus* is a long-ranging Devonian species from Oriskany through Hamilton. In central Ohio it is found in all zones of the Columbus limestone except A, and continues much less sparingly into the Delaware limestone above.

There seems to be little doubt but that specimens of *Paracyclas* in the Dundee of northwestern Ohio are conspecific with those in Michigan, and therefore I am

referring them to *Paracyclas proavia* (Goldfuss). They appear to be identical with those in central Ohio identified as *P. elliptica* Hall. Since uncertainties exist concerning the validity of Hall's type, and the similarity if not identity of the two species is probable, LaRocque (1950, p. 310) concluded that most of the specimens in the middle Devonian rocks in North America probably should be referred to *P. proavia*. One large specimen collected from zone 7, Whitehouse quarry, may belong in a different species.

The remaining species of pelecypods are represented by very few specimens. *Actinodesma occidentale* (Hall) has been identified from zone 4 at Silica, and zone 7 at Whitehouse. It is also represented in the Dundee limestone in southeastern Michigan.

The large and striking cephalopod fauna of the Columbus limestone is reduced to a few insignificant fragmentary specimens in the Dundee. The identifications of the three species included in the general list has been made with reservation, and therefore has little or no stratigraphic significance.

The corals likewise have dropped to a minor position compared with the remarkably rich assemblage of the Columbus limestone. Only 8 species are here reported from the Dundee as of reasonably accurate identification. Interestingly enough however the "Blue limestone" member of the Silica formation above carries a relatively rich coral fauna, and corals are by no means unimportant in the shale phase of the formation. The common reef building *Favositidae* of the Onondaga seas have declined almost to the vanishing point in the Dundee. The only species which seems to be common is the long-ranging *Favosites turbinatus* Billings, which likewise is recognized in Michigan rocks of similar age, and in the middle Devonian limestones of the central belt in Ohio. It is present in the basal zone of the Upper Dundee at Whitehouse and at Silica and is better represented in the basal blue limestone unit of the Silica formation above. The identification of this low, basin-shaped type of coral, with this common middle Devonian species in all these occurrences may be open to question.

No species of the genus *Emmonsia*, so common in the Columbus limestone, have been observed during the progress of this study. *E. emmonsi*, however, is being included since Stauffer (1909, p. 150) reported it from the upper part of his "Columbus" limestone in the Whitehouse quarries.

Perhaps the most distinctive feature of the Dundee corals is the tetracoral *Hexagonaria*, which is represented by at least two species, *H. anna* and *H. tabulata*. These extend upward into the "Blue limestone," where the genus appears to reach its maximum development with 4 species and one subspecies (Stumm, 1948). *Hexagonaria anna*, and *H. tabulata* are found in the Dundee of Michigan, but have not been reported from a lower stratigraphic horizon any place.

As previously mentioned, apart from the striking development of *Hexagonaria prisma* (Lang and Smith) in zone H of the Columbus limestone in the Franklin County region, little evidence of this coral east of the anticline has been observed by the writer. However, Stumm (1948, p. 15, 26) reported two additional species from the Columbus limestone in both central and northcentral Ohio, i.e., *H. ovoidea* (Davis), and *H. curta* Stumm, and one, *Hexagonaria* sp. cf. *H. prisma*, from the Delaware limestone of the northcentral area. If these additional species are valid, a restudy of the Franklin County forms should be made to conform with these more recent interpretations. It is a matter of consequence that *H. prisma* has not been recognized stratigraphically above rocks of Onesquethaw age, i.e., Columbus limestone, Onondaga limestone, and Jeffersonville limestone.

Most of the remaining corals are the more common long-ranging tetracorals, and in all cases very few specimens have been found. The family *Cystiphylloidea* is represented by a single species, *Cystiphylloides "americanus"* (Edwards and Haime), of which only about half a dozen specimens have come under observation from the Silica and Ryan quarry exposures. This species which ranges throughout

rocks of Onondaga to Hamilton age in all the eastern United States is a very common fossil in the Columbus limestone of the Columbus area, particularly in zone H where small individuals occur in a silicified condition along joint surfaces.

Likewise *Heliophyllum "halli"* Edwards and Haime occurs very meagerly in the Dundee limestone, and only three or four typical specimens have been observed. The long, cylindrical type of individual, so common in the Columbus limestone biostrome, has not been recognized. *Heterophrentus prolifica* (Billings) is a more common form, and a few good specimens have been collected from the Whitehouse quarry. The genus has a much greater development in the Silica formation above. The species is likewise recognized in the Dundee of Michigan.

The almost total absence of *Siphonophrentis gigantea* (Rafinesque) is another striking difference from the Columbus limestone, where this largest of all the solitary tetracorals is abundant and widespread throughout all of the central area.

A few specimens are referred with some question to *Zaphrentis phrygia* Rafinesque and Clifford, one of the most common of the Columbus limestone corals, and especially characteristic of zone H. Likewise the prolific *Cystiphylloides "americanus"* of the Columbus has a scant record in the Dundee, and none at all in the Dundee of Michigan or the Delaware limestone.

Judging from the sparce echinoderm remains, there were no flourishing colonies of them in the Dundee seas. During the progress of this study no specimens of blastoids have been observed by me. The species *Nucleocrinus verneuili* (Troost) is included in table 4 because Stauffer (1909) listed it from the "Columbus limestone," although he himself did not collect it. However it is reasonable to expect this common Devonian genus to be represented, especially since it is in the Silica formation above. Kier (1952) recognized one specimen from unit 13 of the Silica shale which he provisionally identified as *Nucleocrinus* sp. cf. *N. elegans* Conrad. In addition he described a new species of the family Pentremitidae, i.e., *Pentremitidea reimanni* from the same beds. To my knowledge this is the first time the genus *Pentremitidea* has been reported from Devonian rocks in the State.

Crinoidal fragments have been collected but are confined almost exclusively to columnal plates. One fragmentary calyx was obtained from the highest unit of the Dundee limestone in the Silica quarries which has been tentatively identified as *Dolatocrinus* sp. In contrast unit 13 of the Silica shale above carries a remarkably well preserved crinoid fauna, some species of which were originally described by me (Stewart 1927), but additional ones including 4 genera, 3 of which are new, and 5 new species were described by Kier (1952).

At times bryozoa flourished in the Dundee sea, and living conditions probably simulated pretty much the same as those for the Delaware in the central area. Their remains occur in diminished distribution and abundance over the Columbus limestone fauna. The order Cryptostomata still prevails but the broad, fan-like fronds of the Fenestrellinidae are much less in evidence, and much more conspicuous are the ramose, branching forms as exemplified in the genus *Sulcoretepora*. Species of this genus are commonly referred to the widely recognized Onondaga form *S. gilberti* (Meek), which is likewise reported from the Dundee of Michigan, and from both the Columbus and Delaware limestones in the central belt. Because of the rather notable concentration of bryozoa in zone 4 of the Dundee at the Silica quarries, and the correlative zone 8 at the Whitehouse quarry, this zone is commonly referred to as the "bryozoa zone." Trepostomatous bryozoa are likewise well represented in this zone by headlike masses of the genus *Monotrypa* or an allied form. The majority of the bryozoa though, are in the Silica formation, where they occupy a much more important role in the total fauna than in the Dundee below.

Recent studies of Kesling (1954) have revealed an interesting ostracode assemblage in unit 4 of the Dundee limestone (Ehlers et al. 1951, p. 18) exposed by the quarrying operations of the France Stone Company, just west of Sylvania Avenue

near Silica. No ostracodes have been described from the Dundee limestone in Ohio before although they were known to be present. The specimens are all from the weathered chert nodules and layers, and Kesling describes them as being incompletely silicified, with complete carapaces, in many cases exhibiting fine details of surface structure. Details of this structure are beautifully shown in the three plates of illustrations in his publication.

The fauna is not large, 6 genera and 5 species, but is distinctive because 2 of the genera and all of the species are new. The new genera are *Endolophia* and *Trypetera*, and the previously described ones are *Garychilina*, *Dizygopleura*, *Hollinella*, and *Octonaria*, all long-ranging Paleozoic forms.

This fauna does not seem to have a counterpart in rocks of similar age in any other part of Ohio, but the closest approach is in the ostracodes that have been found in Bone Bed No. 3 of the Delaware limestone in Franklin County. (Stewart 1950). This fauna is larger in point of genera and species, but not in individuals. Twenty-one genera and 18 species have been recognized, some of questionable identification. The specimens are ferruginous and the preservation far inferior to the Dundee material. The writer pointed out the apparent similarity between the Delaware fauna and that of the Jeffersonville limestone of Kentucky both in generic and specific content.

On the other hand the resemblance between the Delaware and Dundee faunas is not so evident. There are two genera in common, i.e., *Dizygopleura* and *Hollinella*, but no species. Each genus is represented by one named species in each formation, i.e., *D. compsa* Kesling and *H. variopapillata* Kesling from the Dundee, and *D. trisinuata* Van Pelt, and *H. kolmodini* (Jones) from the Delaware. The latter species is middle Devonian in range, and *D. trisinuata* was reported previously from the Plum Brook shale of Ohio (Stewart and Hendrix, 1945). The genus *Dizygopleura* is especially well represented in Onondaga and Hamilton age rocks in the eastern part of the United States.

Trilobite remains are few and fragmentary. Only pygidia have been observed in the course of this study, none of which is entirely complete. Four genera and 4 species of the families Proetidae and Phacopidae are listed in table 4, but the writer was able to identify only two of these in material studied.

So far as present knowledge goes the proetid types are best represented but by extremely meager remains. Three species belonging in 2 genera have been reported, but the writer is reasonably sure of the identification of only one species: *Dechenella* (*Dechenella*) *planimarginata* (Meek). The material on which the identification is based consists of pygidia: about one half dozen exfoliated specimens from zone 4 of the Silica quarry, (see table 4) incomplete external molds of two pygidia from zone 6 of the same quarry, and one exfoliated pygidium from zone 7 of the Whitehouse quarry. The species was named and described by Meek (1871, p. 89, and 1873, p. 223) from an exfoliated pygidium from the "upper part of the Corniferous group, near Sylvania, Lucas County, Ohio." Bassett (1935, p. 441) and Stumm (1953, p. 20) reported the species from the Dundee of Michigan. No other occurrence of it is known. As previously mentioned the trilobites formerly identified with *D.* (*Dechenella*) *planimarginata* from the Columbus limestone in central Ohio should be restudied and probably renamed. Stumm does not recognize the species in the northcentral region.

Stauffer (1909, p. 102) listed *Dechenella* (*Basidechenella*) *rowi* (Green) from the Dundee ("Columbus") limestone but did not collect it. Stumm in his study of the proetids did not recognize the species outside of the Marcellus formation of western New York, but described a subspecies *sanduskiensis* from the Delaware limestone of the northcentral region. *D.* (*Basidechenella*) *rowi* appears to be restricted to rocks of Hamilton age. As already mentioned many specimens in the Columbus limestone in both the central area and in the Bellefontaine outlier have in the past been identified with this species, and probably should be restudied.

On the other hand those from the Delaware limestone seem to be indistinguishable from the Marcellus forms, and it seems best to continue to identify them with *D. (Basidechenella) rowi* until such time as a more critical study of them can be made.

It is noteworthy that no specimens of the distinctive and commonly occurring *Proetus (Crassiproetus) crassimarginatus* Hall of the Columbus limestone of the central area have been recognized in any of the material which has come under survey, although Stauffer (1909, p. 151) reported it from the highest horizon of his "Columbus limestone," in the Whitehouse quarries. Bassett (1935, p. 441), listed the species from several intervals of the Dundee limestone in the Sibley quarry in southeastern Michigan, but Stumm (1953) does not recognize it there. The species is widely distributed in rocks of Oriskany and lower Middle Devonian age throughout the eastern half of the continent.

Evidence of Phacopid trilobites is scarce but identification of two genera seems reasonably certain: *Coronura* and *Phacops*. The only record of *Coronura* is in zone 3 of the Ryan quarry, where a rock specimen containing the impression of a portion of the pygidium of a large-tailed trilobite has been collected. This sparse record is in striking contrast to the splendid development of the genus in the Columbus limestone in the Franklin County region where *Coronura aspectens* (Conrad) is such a common fossil. The genus is known only from Middle Devonian rocks in eastern North America, and the species is restricted to the lower half (Onesquethaw).

Zone 7 at Whitehouse has yielded a few fragmentary pygidia of *Phacops* which are assigned tentatively to *P. cristata* Hall. It is questionable whether the species extends above rocks of Onondaga age.

The poor showing of *Phacops* in the Dundee is rather surprising, since it appears in such abundance in the Silica formation above and in the Traverse of Michigan. Likewise it is well represented in the Middle Devonian limestones of the central area, where *Phacops cristata* is found distributed throughout the Columbus limestone. *Phacops rana* (Green), a Hamilton species, is recognized in the Delaware limestone and Olentangy shale. *P. cristata* has a stratigraphic range through Oriskany, Schoharie, and Onondaga rocks in New York and other eastern states.

Meager remains of fish seem to be the only evidence of vertebrate remains in the Dundee limestone. Only one described species appears in the literature: *Dipterus eastmani* Stauffer, based on one upper, dental plate, from the upper part of the Dundee ("Columbus") limestone in the Whitehouse quarry. One fragmentary specimen in our collections, undoubtedly a fish plate, was obtained from the upper Dundee in the Ryan quarry.

The paucity of fish remains is surprising when one considers that the Devonian rocks on the eastern flank of the Cincinnati anticline in Ohio are classic for their fossil fish. Newberry's famous material seems to have come exclusively from this latter region.

Bone bed accumulations such as are developed in the Columbus and Delaware limestones have no counterpart in the Dundee. Their absence is perhaps not unusual since the special conditions which produced these accumulations of organic materials probably never did exist in this region when the sediments were deposited. According to Wells (1944), the bone beds represent a thanatocoenose assemblage of fresh water fish mostly, accumulated in a shallow sea, bordering the land area of Cincinnati. Their origin is diastemic, in that they developed largely as lag concentrates where the sea bottom fluctuated above and below wave base. Since northwestern Ohio was further removed from the land area, the water would probably be deeper, and the concentration of such material would be extremely unlikely.

So far no conodonts have come to light in the Dundee limestone. They may be present but have not been recognized. The fact that in the Columbus and Delaware limestones conodonts have been recovered from the bone beds only,

does not mean necessarily that they are not likely to be found in other lithologic surroundings, which after all possibly approximate more closely the natural biocoenose of the living organism.

Apart from some carbon imprints of probable plant origin, the only record of plants is in the spores of the ancient marine algal trochilisk, *Eutrochiliscus devonicus* (Wieland). Specimens have been observed and collected in two places: zone 6 of the Silica quarry, and zone 4 of the Ryan quarry where they occur in clusters associated with the brachiopod *Cyrtina*. The specimens from the Silica quarry are larger than normal for the species, and are characterized by 10 sharp, curving ridges, similar to *Eutrochiliscus bellatus*. Dr. Raymond Peck kindly inspected the specimens, and was of the opinion they should all be referred to *E. devonicus* because of the difficulty in making fine specific distinctions on the basis of the present state of knowledge on the trochilisks.

Plant spore exines of a similar nature have been reported from numerous places in the Columbus limestone, and erroneously identified as a protozoan, *Calcisphaera robusta* Williamson. Meek, however, (1873, p. 219) was the first to suggest these minute bodies might be the fruit of *Chara*.

Modern trocholisks are fresh water forms.

SUMMARY AND CONCLUSIONS

From the foregoing considerations on the stratigraphic and faunal relationships of the Middle Devonian limestone formations in Ohio it is believed the following pertinent facts have been established and are acceptable:

1. The Dundee ("Columbus") limestone of northwestern Ohio should be correlated with the Dundee of Michigan on a stratigraphic, lithologic, and paleontologic basis.

2. Stratigraphically the Ohio Dundee is a thinning southward extension of the Dundee formation of Michigan, having a maximum thickness of 61½ ft. at the Silica quarries. The thickest exposure in Michigan is about 70 ft. in the Solway Process Company's quarry, near Trenton, Wayne County.

3. Lithologically the Dundee is similar in the various exposures observed, although in Michigan the rock is generally more coarsely crystalline, while in Ohio the lower two-thirds of the formation is more dolomitic in character and contains more chert.

4. Faunas are essentially similar geographically throughout the Dundee, although by no means identical. Species limited to the Dundee or similar-age formations are: *Atrypa elegans*, Grabau, *Brevispirifer lucasensis* (Stauffer), *Rhipidomella variabilis* Grabau, and *Dechenella* (*Dechenella*) *planimarginata* (Meek).

5. The Dundee rests with disconformable contact on the Anderdon limestone of the Detroit River group, and is the approximate age of the Marcellus formation (Lower Cazenovia) of New York State, and the Delaware limestone in Ohio and southwestern Ontario. This correlation has been recognized by Cooper et al. (1942, p. 1754), and Ehlers et al. (1951, p. 26). This author is in agreement with the above interpretation.

6. Faunal similarities between the Dundee and the Delaware limestones are to be found in species common to both such as: *Brevispirifer lucasensis* (Stauffer), *Atrypa costata* Bassett, *Actinodesma occidentale* (Hall), *Paracyclas proavia* (Goldfuss), and *Tentaculties scalariformis* Hall.

7. The Columbus limestone of central Ohio rests with disconformable contact on the upper Bass Island group, and is the approximate age of the upper Onondaga limestone (upper Onesquethaw) of New York State, and the Jeffersonville limestone of southeastern Indiana and northern Kentucky.

8. The formations listed in item 7 above have many species in common. Characteristic forms are: *Hexagonaria prisma* (Lang and Smith), *Zaphrentis phrygia* Rafinesque and Clifford, *Siphonophrentis gigantea* (Lesueur), *Brevispirifer*

gregarious (Clapp), *Paraspirifer acuminatus* (Conrad), *Nucleocrinus verneuili* (Troost), *Phacops cristata* Hall, and *Coronura aspectens* (Conrad). These species are either missing or questionably present in the Dundee of northwestern Ohio.

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Chemical Calculations. *H. V. Anderson.* McGraw-Hill Book Company, Inc., New York. Sixth edition, 1955. viii+305 pp. $4.75.

This volume provides a very useful arrangement and choice of information for the beginning student in college chemistry. Introductory sections on weights and measures, significant figures, dimensional analysis, and exponents should aid the student who wishes to help himself with these topics, which are sometimes overlooked or assumed as background in the course of instruction. The chapters in traditional problem areas are well supplied with understandable examples and include sound problems of varying difficulty. Problems and discussion are presented on the gas laws, Mole-weight-gas volume relationships, chemical formulas, electrochemistry, oxidation-reduction, concentration and equivalency, thermochemical processes, equilibria, and a number of other subjects. The approach is generally traditional and tends to emphasize an understanding of the relationships involved rather than mechanical manipulation of mathematical formulas.

In a few cases, the language seems unfortunate. For example, the simultaneous oxidation and reduction of chlorine upon contact with base is termed "internal oxidation and reduction". This phenomenon is probably more often termed "disproportionation". The use of the term "valence number" as synonymous with oxidation state may confuse the student who has previously studied the section on valency.

The scope of the discussion, which is, of course, entirely a matter of the author's choice, is occasionally difficult to appreciate. While a very clear and adequate treatment is given to most of the phenomena normally discussed at this level, some topics are omitted. The entire problem of complex formation, and the dissociation equilibria related thereto, is ignored. This seems strange since the relationships involved in the precipitation of sulfides, which are equally difficult and which find their pertinence at about the same stage of development of the student, are discussed. It might also be suggested that the discussion of the calculation of degree of ionization from experimental data would make the problems involving degree of ionization of weak electrolytes more meaningful.

There is no question but that this book will be of much value both to the student and to the instructor. The student will find the illustrative examples informative and easy to follow while the instructor will find much to aid him in the preparation of quizzes and problem assignments.

DARYLE H. BUSCH

MISSISSIPPIAN–PENNSYLVANIAN UNCONFORMITY NEAR ADAMS MILLS, OHIO

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An interesting exposure of the Mississippian-Pennsylvanian unconformity occurs in a road cut on Ohio State route 16 one mile west of Adams Mills, Muskingum County. The locality is about one-half mile south of the Coshocton County border on the north side of Monroe Basin of the abandoned Ohio Canal.

The unconformity is well exposed for a distance of approximately 400 ft. along the cut, which trends about N 80°E. Three very small Mississippian "hills" and two "valleys" occur with a maximum exposed relief of 15 ft. The lower part of the "valleys" is covered. The slope angles on each side, however, indicate that the bottoms lie only a few feet beneath the cut, and the total relief is thought to be about 20 ft.

The exposed Mississippian rocks consist of approximately 15 ft. of light-grey, massive, fine-grained sandstone. This sandstone is probably part of the Waverly series but the particular formation was not determined. No fossils were observed. The sandstone is weathered just below the unconformity and is stained with iron oxide. At the east end of the cut a red clay lies above the sandstone and apparently beneath the line of unconformity. This clay is poorly exposed but occurs beneath a relatively level part of the unconformity and may be a fossil soil. Pennsylvanian light-colored clays containing plant remains occur above it. The line of unconformity in the cut is for the most part very sharp.

Overlying the Mississippian are grey to black, carbonaceous, concretionery, fissile shales grading upward into sandstone. The thickness and details of composition vary in each "valley" and over the "hill" tops. These sediments are thought to belong to the basal Pennsylvanian Pottsville formation. A few poorly preserved plant fossils were found. A thin layer of coaly material lies along the unconformity near the bottom of the western "valley" indicating that at least a part of this surface was covered with vegetation.

These lower Pottsville sediments exhibit the phenomenon of compaction similar to that described by Ver Steeg (1948) to the north in Wayne County. The fissile carbonaceous shales on the sides of the "valley" overlap each other layer by layer, indicating that the valleys filled slowly until the sediments covered the "hills". Compaction began as the sediments accumulated, and the sediments became bent into anticlines and synclines. Compaction was probably caused chiefly by expulsion of water.

The thickness of the section involved in the compaction folding is not known, as a local Pennsylvanian erosion surface cuts across the dipping sediments. Apparently, sediments were deposited on the unconformity and compacted, then deposition ceased and erosion removed a part of the sediments. Later, erosion ceased and deposition was resumed. Above the local unconformity thus produced the sediments are essentially horizontal and show no compaction folding.

The basal bed in this upper section is a medium grained, cross-bedded sandstone with a maximum thickness of about 2½ ft. It is resistant to weathering and generally forms a ledge. A similar appearing but thinner sandstone, also ledge forming, occurs in some parts of the upper portion of the compaction folded sediments. It is cut off near the tops of the compaction anticlines by the local erosion surface. Both this sandstone and the bed in the sequence above are underlain by a thin layer of clay and coaly material.

THE OHIO JOURNAL OF SCIENCE 55(3): 182, May, 1955.

FIGURE 1. Unconformities in road cut west of Adams Mills, Muskingum County, Ohio. Lower ink line drawn along Mississippian-Pennsylvanian unconformity; upper ink line drawn along a local Pennsylvanian unconformity.

FIGURE 2. A small "hill" cut in Mississippian rocks. Pennsylvanian sediments are compacted over the "hill". Upper ink line indicates local Pennsylvanian unconformity. Note sandstone bed on right side of "hill" cut off near the crest by the upper erosion surface.

Only the lower few feet of this upper sequence are well exposed. Above the cross-bedded sandstone is a shale of unknown thickness containing some thin sandstone layers. Several feet farther up the hillside, bluish-black, fossiliferous flint and limestone crop out. This may be the Boggs member of the Pottsville described by Stout (1918) in northern Muskingum County.

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Human Embryology. *Bradley M. Patten.* The Blakiston Company, Inc., New York. Second edition, 1953. xvii+798 pp. $12.00.

Recent contributions in two widely different aspects of human development have induced the author to prepare a second edition of this well known and widely used text.

Since the publication of the first edition in 1946 younger embryos than any heretofore known have been recovered. These include cleavage, blastodermic vesicle and implantation stages. Chapter 4 entitled Cleavage, Germ Layers and the Establishment of the Embryonic Body, and Chapter 6 dealing with Fetal membranes and Placenta have been extensively reviewed and expanded on the basis of this new material.

The notable recent progress in the handling of congenital cardiovascular defects has emphasized the importance of a thorough knowledge of the development of the heart and large blood vessels. The material on this subject in Chapter 19 has been expanded and a number of illustrations in color added.

Only minor changes have been made in other chapters of the book. However, a supplement to the bibliography has been added which includes pertinent articles published between 1945 and 1952. This book is designed for medical students and medical practitioners but it will serve as a useful reference in elementary courses in embryology. R. A. KNOUFF.

Naturalists Directory. Published by the Naturalists Directory, 720 Fillmore Road, East Meadow, N. Y. 37th Edition, 1954. $5.00 postpaid.

This latest edition of the familiar *Naturalists Directory* should prove a helpful reference book to those interested in the study of nature in any of its branches.

F.W.F.

The Biochemistry of Genetics. *J. B. S. Haldane.* George Allen and Unwin, Ltd., London. 1954. 144 pp. $2.75.

A genetically determined variation has a biochemical basis. The foregoing statement is the central thesis of J. B. S. Haldane's recent volume concerning the biochemistry of genetics. Following an introductory chapter on the elements of genetics, the reader is brought up to date on the biochemical genetics of blood antigens, haemophilia, fungi, bacteria, viruses, plant pigments, animal pigments, and "inborn errors of human metabolism." The author points out that although genes control biochemical processes, the control is usually remote, and through the action of enzymes. He believes we are approaching the time when we can specify what a gene or a group of them does, but not through the investigation of gene controlled processes. Instead, it will be through investigations of the synthesis of molecules of moderate size, such as those occurring in Neurospora.

Haldance discusses extranuclear influences on biochemical activity, including training, and various interpretations of the latter phenomenon. Summing up this discussion he states "some workers . . . while probably not denying the existence of adaptive enzymes, appear to deny that their synthesis continues, or is in any way facilitated when the stimulus to it ceases. It is reasonable to adopt this view as a working hypothesis during a critical examination of results . . . , but to adopt it without further ado to explain such results is, in my opinion a piece of dogmatism as regrettable as that of Lysenko in the opposite direction."

This small volume is written in a clear, logical and interesting fashion. Those wishing to keep abreast of developments in biochemical genetics and their philosophical implications can ill afford to neglect reading it.

DAVID C. RIFE

METHANOL TOLERANCE OF THREE STRAINS OF *SACCHAROMYCES CEREVISIAE* HANSEN[1]

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That the ethanol produced in the fermentation of glucose by yeast eventually reaches a concentration at which it prevents further conversion of substrate is a well-known fact. In a systematic study of a number of yeasts Gray (1941) has shown that this inhibitory concentration, while varying widely among different yeasts, is characteristic enough for a given species or strain that definite "alcohol (ethanol) tolerance" values may be assigned. An empirical relationship between these alcohol tolerance values and the amounts of reserve materials formed, especially fats, has been described (Gray, 1948).

Results of a preliminary attempt to acquire information concerning the mechanism of this ethanol inhibition indicated that the alcohol may exert its effect on glucose utilization in a culture by limiting the size of the active cell population (Troyer, 1953). Since limitation of multiplication is a rather general effect, it is important to know whether the phenomenon of alcohol tolerance hinges around specific properties of ethanol alone or whether related substances may not produce similar effects. In the present work this question has been investigated by ascertaining the effects of added methanol upon the utilization of glucose by three yeasts.

EXPERIMENTAL

The three strains of *Saccharomyces cerevisiae* Hansen employed in this study were Nos. 1 (D. C. L. strain), 28 (Rasse M strain), and 31 (Brown-Forman strain) of the culture collection of the Ohio State University Department of Botany and Plant Pathology. The ethanol tolerances of these yeasts have been studied (Gray, 1941). A liquid glucose-phosphate-yeast extract medium (Gray, 1946) was used in 125-ml. Erlenmeyer flasks, each of which contained 50 ml. of liquid. Procedural details in the preparation, sterilization, and inoculation of the cultures were similar to those previously described (Troyer, 1953), with the sole exception that methanol instead of ethanol was added in varying amounts to the vessels. Cultures were maintained without shaking at 30° C for 24 hours. Initial and final glucose concentrations were estimated by the method of Stiles, Peterson, and Fred (1926). The initial cell count in each case was 1 x 10^6 per ml., while the initial glucose concentration was 10.10–11.12 mg. per ml.

RESULTS AND DISCUSSION

The results obtained in this study are summarized in figure 1. Increasing the concentration of methanol in the culture medium up to a certain point had little effect on the utilization of glucose by the three yeasts. Above this critical level, which appeared to be characteristic for each yeast, a further increase in methanol concentration was accompanied by decreased glucose utilization. In general the sigmoid curves of figure 1 resemble the response curves usually obtained in studies of this kind. In this respect these results are similar to those reported for the inhibition of glucose utilization in these yeasts by ethanol (Gray, 1941). It may be supposed that for each yeast there is a critical methanol concentration

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above which the utilization of glucose is inhibited—in other words, that each yeast possesses a certain methanol tolerance. By analogy with the concept of Gray (1941) this tolerance value might be defined as the maximum concentration of methanol at which the percentage of glucose utilized is no more than one percent below the percentage of glucose utilized in the absence of methanol. Other definitions would, of course, be possible.

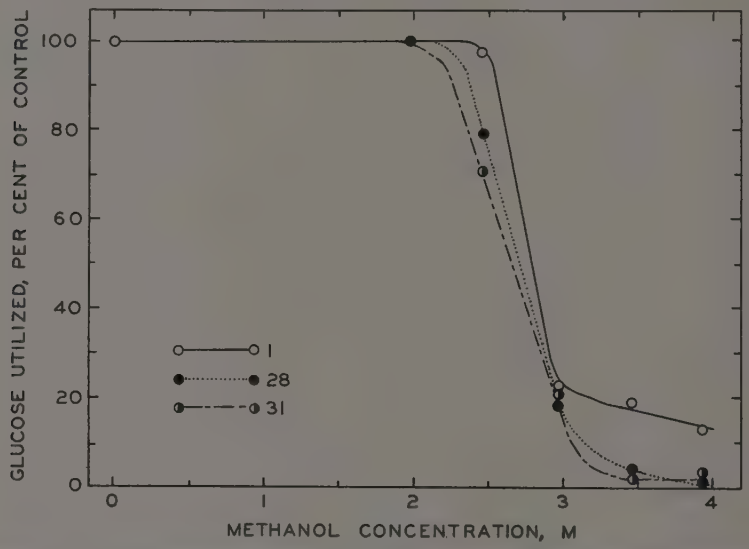

FIGURE 1. The effect of added methanol on glucose utilization by three strains of *Saccahromyces cerevisiae* Hansen. Methanol concentration is expressed in terms of molarity of the final solution in the culture flasks. The amount of glucose utilized in each instance is expressed as a percentage of that utilized in the control cultures to which no methanol was added. Each point represents the mean value for duplicate cultures.

As might be expected, yeasts appear to vary in methanol tolerance. If the strains studied here are ranked on this basis, the order is $1 < 28 < 31$. Curiously, this order is exactly the reverse of that reported for the ethanol tolerances of these same yeasts; when ethanol tolerance is measured as reductions in either glucose utilization (Gray, 1941) or population size (Troyer, 1953), the order is $31 < 28 < 1$. Since only three strains were considered in this investigation, little importance should now be attached to this observation; it seems likely that the inversion of order might not hold if additional yeasts were to be studied. If the present results are compared with those of Gray (1941), methanol appears to be less inhibitory to the processes of glucose utilization in these yeasts than is ethanol. The methanol tolerance values (as molarities) for yeasts 1, 28, and 31, respectively, were 2.42 M, 2.20 M, and 2.00 M. If the data of Gray are expressed as molarities to facilitate comparison, the ethanol tolerance values are, in the same order, 1.29 M, 1.77 M, and 1.93 M.

The overall similarity of the results reported here to those previously secured in studies of the effects of ethanol on the same yeasts suggests that the phenomenon of alcohol tolerance may be rather non-specific in nature: the action of ethanol in

inhibiting glucose utilization may be associated with its properties as a member of a general class of substances, rather than with its role as a yeast metabolite. Of course, the economic significance of the inhibition is not lessened by the conclusion that limitation of fermentation by ethanol is perhaps only an incidental consequence of its formation.

SUMMARY

The effect of added initial methanol on the utilization of glucose by three strains of *Saccharomyces cerevisiae* Hansen has been studied. The observed inhibition resembles that previously obtained with ethanol. It is suggested that this result indicates that the ethanol tolerance phenomenon may not devolve directly upon the fact that ethanol is a yeast metabolite.

ACKNOWLEDGMENT

Grateful acknowledgment is made to Dr. W. D. Gray, Professor of Botany in The Ohio State University, for his helpful counsel.

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Within the Living Plant (An Introduction to Plant Physiology). *Erston V. Miller.* The Blakiston Company, Inc., Garden City, New York. 1953. ix+325 pp. $5.00.

In this new text, designed for a one-semester course, the author has two goals: (1) to present the fundamental principles of plant physiology, and (2) to focus attention on the manner in which plant physiology affects everyday life. Other authors have found it difficult to attain the first objective in larger texts; the superficial treatment which many principles receive here is therefore unavoidable. Chapters three, four, and part of five present a hasty survey of the physics and chemistry considered pertinent to plant physiology. Sometimes a concept is spelled out in great detail, viz. p. 16 where rigorous proof is presented to convince the student that $95 \times .17 = .95 \times 17$. More frequently, however, it is assumed that the student has a profound understanding of difficult concepts which are discussed in highly condensed fashion, viz. references to quantum theory and the law of photochemical equivalence in the chapter on photosynthesis. There are frequent digressions into general botany, history of biology, ecology, soil science, and economic botany. Teachers who like to include such digressions in lecture will find a store of them here. As a textbook of Plant Physiology it seems inadequate. JACOB VERDUIN

Directory of International Scientific Organizations. Published by U.N.E.S.C.O., distributed by Columbia University Press, New York. Second edition, 1953. 312 pp. $2.50.

This directory lists the names, in English and French with official abbreviations, addresses, and pertinent information concerning some 250 international scientific organizations.

F.W.F.

Geology of Coshocton County. *Raymond E. Lamborn.* Bulletin 53, Divn. of Geological Survey, Ohio Department of Natural Resources, Columbus. 1954. ix+245 pp. $3.00.

This bulletin includes a description of the sequence of rocks in Coshocton County, particularly with reference to their economic utilization. It includes a large, folded geologic map of the county. Copies may be obtained from the Div. of Geol. Survey, 106 Orton Hall, Ohio State University, Columbus 10, Ohio.

F.W.F.

A SYNOPSIS OF THE GENUS COPHES IN THE UNITED STATES AND MEXICO (COLEOPTERA, CURCULIONIDAE).

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The purpose of this paper is to review the North American species in the genus *Cophes* Champion, and aid other workers in determining these species. The genus was first recorded as occuring in the United States by the late Dr. E. C. Van Dyke in 1930. He recorded *Cophes gibba* Champion as occuring in Arizona. However, he mistook a species of *Gasterocercus* (sens. lat.) for *gibba*. Two forms are here listed as occuring in the United States. One is new to science.

I am indebted to Sir G. A. K. Marshall of the British Museum (Natural History) for his help and information on the members of the genus and for making comparisons with the types. I am also indebted to Mr. Barry D. Valentine of Harvard College and Miss Rose E. Warner of the United States National Museum for their comparisons and help. Mr. H. B. Leech of the California Academy of Sciences kindly sent me the material studied by Dr. Van Dyke.

Key to the species of *Cophes* occuring in North America

The * indicates that the species occurs only in Mexico.
The † indicates that the species occurs in both the United States and Mexico.

1. Anterior femora bidentate; the outer tooth frequently small..... *longiuscula* (Boheman)†
1'. Anterior femora unidentate..... 2
2. Eyes widely separated, nearly as wide as rostrum at base..... 3
2'. Eyes narrowly separated, about one-third as wide as the rostrum at base..... 4
3. Second segment of funicle longer than first; elytral intervals 3, 5, 7, and 9 elevated; metaepisterna narrow..... *cognata* Champion*
3'. Second segment of funicle subequal to the first; elytral intervals 3 strongly elevated, 5 and 7 moderately elevated; metaepisterna wide..... *texana* n. sp.†
4. Second segment of funicle longer than first; elytral intervals 3, 5, and 7 elevated, the first strongly raised and swollen anteriorly in male; anterior legs of male much longer than those of female..... *gibba* Champion*
4'. Second segment of funicle subequal to first; elytral intervals flat; anterior legs of both sexes equal..... *hieroglyphica* Champion*

Cophes Champion

Cophes Champion 1905, p. 515. Van Dyke 1930, p. 164.

Rostrum curved, cylindrical, moderately stout, reaching to about the middle of the mesocoxae in the ♀; separation of eyes variable, rather prominent. Antennae with funcile 7-segmented, 2 sometimes longer than 1. Club oblong or ovate. Prothorax transverse, bisinuate at the base, the ocular lobes feebly developed. Scutellum rounded or oval. Elytra as wide or wider than the prothorax; tenth striae abbreviated. Metasternum moderately long; ventral abdominal segment 2 a little longer than 3. Anterior legs more or less elongated in the ♂; femora moderately or feebly clavate; posterior pair not extending beyond apex of the elytra; anterior tarsi of the ♂ clothed each side with long projecting setae.

Genotype: *Cryptorhynchus longiusculus* Boheman.

The genus *Cophes* should be placed after *Coelosternus* Schönherr in the Leng Catalogue. It differs from the latter in the relatively longer second ventral abdominal segment and the shorter stouter rostrum. From *Macromerus* it differs in having shorter legs, the anterior pair less elongated in the male, the rostrum is shorter and stouter, reaching to about the middle of the mesocoxae, and the mesosternum is horse shoe-shaped or triangular.

Cophes longiuscula (Boheman)

Cryptorhychus longiusculus Boheman 1837, p. 217.
Cophes longiusculus (Boheman), Champion 1905, p. 516.

Oblong-ovate: black with the antennae and last tarsal segment reddish brown; densely clothed with pale brown and white scales, the white scales condensed in an elongate, fusiform spot on the pronotum; the side of the prothorax densely clothed with brown scales; the disc of the elytra mottled with brown and white scales.

Rostrum as long as pronotum; slightly curved; finely closely punctured; a smooth median line present throughout length in ♀. Antennae inserted at middle in ♂, just behind middle in ♀. First and second segments of funicle equal. Club elongate-ovate. Head closely, coarsely punctured. The eyes separated by the width of the rostrum at base.

Prothorax wider than long; the sides curved in basal two-thirds, then narrowed to a moderately constricted apex; pronotum coarsely, rugosely punctured; a median carina present in basal two-thirds. Scutellum small, rounded.

Elytra long, wider than prothorax; the sides parallel in basal two-thirds, then rounded to apex; humeri feebly rounded; striae serially punctured; intervals 3, 5, and 7 strongly elevated, intervals 1, 3, and 5 with prominent asperites, each asperite with a clavate recumbent pale brown scale.

Ventral side sparsely clothed with pale brown and white scales; the abdominal segments finely sparsely punctured, the fifth with a few scattered coarse punctures also. Legs elongate, those of ♂ longer than in ♀. Femora clavate, the anterior pair bidentate, the middle and posterior pair unidentate. Anterior tarsi of male broadly dilated.

Length 5.5–9.5 mm., width 2.8–3.1 mm.

Distribution.—The types were from Vera Cruz, Mexico, Chevrolat Collector. Examples are also known from Playa Vicente, Mexico, Salle Collr.; Chontales, Nicaragua, Janson Collr.; Cuernavaca, Morelos, Mexico, VI–45, N.L.H. Krauss; Santa Rosa, Costa Rica, Schlitz Collr.; and Brownsville, Texas. There are examples from the latter locality in the United States National Museum, the Canadian National Collection, Ottawa, and the author's collection.

This species is readily separated from all other species in the genus from the area under consideration, by the very elongate form and the bidentate anterior femora.

Cophes cognata Champion

Cophes cognatus Champion 1905, p. 518.

Elongate-ovate; black with the antennae reddish brown; densely clothed above with brown scales, the pronotum and disc of elytra more or less mottled with black and dark scales condensed in two triangular spots at the base of the pronotum and condensed in irregular spots behind the scutellum, the latter brownish yellow; the dorsum with short scattered, setiform scales.

Rostrum a little longer than pronotum, strongly curved, rugosely punctured and carinate at base, the remainder sparsely punctured, smoother in the ♀. The antennae inserted towards the base in ♀, and near middle in ♂. First and third segments of funicle equal in length, second more elongate. Club ovate. Head rugosely punctured, the eyes separated by nearly the width of the rostrum at base.

Prothorax transverse, rounded at the sides, narrowed and constricted apically, also narrowed basally: pronotum densely, finely punctured and carinate. Scutellum rounded, large.

Elytra moderately long, wider than the prothorax, the sides subparallel in the basal third and considerably produced at the apex; the humeri rounded; striae serially-punctured; intervals rugose and granulate, 3, 5, 7, and 9 raised, the suture elevated except near the base.

Ventral side densely punctured; densely clothed with brownish scales. Legs moderately long. Femora unidentate. Anterior tarsi of the ♂ with a few long, laterally projecting setae.

Length 7.0–8.5 mm., width 3.0–3.5 mm.

Distribution.—Three cotypes from Cerro Zunil, Guatemala, Champion Collr. and one Toxpam, Mexico, Salle Collr. These are the only examples know to the author.

Cophes texana n. sp.

Male.—Oblong-ovate, robust; black with the antennae reddish brown; densely clothed above with pale brown and white broad oval scales and narrow clavate pale brown scales; the white scales condensed in a narrow line on the pronotum and extends onto the head, and scattered over the disc of the elytra, the brown scales scattered over the whole of the head, prothorax and elytra; elytral intervals 2, 4, and 6 with narrow clavate scales in the punctures.

Rostrum three-fourths as long as pronotum, nearly straight; coarsely rugosely punctured and sulcate in basal third; punctures finer apically; a narrow smooth impunctate median line present in apical two-thirds. Antennae inserted just behind middle of rostrum. First and second segments of funicle equal, 3–7 transverse. Club obovate, basal segment composing three-fourths length. Head closely, coarsely, deeply punctured. Eyes separated by the width of the rostrum at base.

Prothorax wider than long, the sides evenly rounded in basal two-thirds then rapidly narrowed to apical constriction; pronotum coarsely, closely, deeply punctured; a small short median carina at middle. Scutellum very small, rounded.

Elytra short, only a little more than one and one-half times as long as wide; the sides parallel in basal half then rounded to apex; humeri rectangular; striae serially punctured, widely separated; intervals 3 strongly elevated, 5 and 7 moderately elevated, elevated intervals asperate, each asperite with a recumbent clavate scale.

Ventral side sparsely clothed with pale brown and white scales; coarsely, deeply punctured; the abdominal segments finely, sparsely punctured. Legs slender but not elongate. Anterior femora unidentate. Anterior tarsi narrow, not dilated.

Length 5.0 mm., width 2.3 mm.

Female.—Rostrum as long as pronotum, much more finely sparsely punctured than male, not as rugose basally, otherwise as in male. Length 5.5 mm. width 2.5 mm.

Distribution. Holotype, ♂, and allotype, ♀, Pharr, Texas, IV–7–45, C.C. Wilson, in the author's collection. Twenty paratypes deposited as follows: in the author's collection, 1 ♂, 3 ♀, same data as holotype, 1 ♂, 2 ♀, La Paloma, Texas, IV–14-42, W.C. Nelson, 1 ♂, Brownsville, Tex., IV–30–04, H.S. Barber; in the British Museum (Natural History), 1 ♂, 1 ♀, La Paloma, Texas, IV–14–42, W.C. Nelson; in the United States National Museum, 1 ♀, La Paloma, Texas, IV–14–42, W.C. Nelson, 2 ♀, Brownsville, Tex., VII–28–32, 3 ♀, Brownsville, Tex., VI–5–32, E. G. Linsley, 1 ♀, Brownsville, Tex., VI, Wickham, 1 ♀, Brownsville, Tex., VIII–21–44, 1 ♂, Brownsville, Tex., IV–30–04, H. S. Barber, 1 ♂, Esprz. Ranch, Brownsville, Tex., VI, Schaeffer. Length of paratypes 5.2–7.0 mm., width 2.3–3.1 mm. There is a single example in the author's collection from Guerrero, Mexico which is not included as a part of the type series.

This species is nearest *quadricostata* Champion from Panama, differing in the second segment of the funicle equal to the first, the intervals 3, 5, and 7 are more strongly elevated, there are no black scales present nor any condensed spots of dark scales on the elytra, and the anterior femora are unidentate not bidentate.

Cophes gibba Champion

Cophes gibbus Champion 1905, p. 517.
Coelosternus gibbus Chevrolat in litt.

Oblong-ovate; black; mottled above with a dense clothing of intermixed white, brownish yellow, and black scales, the black scales sometimes condensed into a small oblong patch behind the scutellum and the whitish ones into a faint sub-apical fascia.

Rostrum as long as the pronotum, moderately stout, in ♂ rugose, subcarinate at base, thickly punctured from there to the apex, in ♀ almost smooth from base to apex. The antennae inserted at about the middle, segment 2 of funicle shorter than first, 3–7 transverse. Club stout, ovate, with oblique sutures. Head rugosely punctured. Eyes extremely large, finely facetted, and separated by about one-third the width of the rostrum.

Prothorax broader than long, much narrowed to apical constriction; sides rounded basally; pronotum sparsely, finely, irregularly granulate and minutely punctured.

Elytra oblong, not or very little wider than prothorax, the sides more parallel in the ♀ than

in the ♂; striae coarsely, serially punctured and more or less granulate or asperate; intervals 3, 5, and 7 elevated, the first interval swollen and arcuate anteriorly in the male.

Ventral side and legs clothed with white scales; the femora slightly annulate with brownish yellow or brown. The abdominal segments finely and shallowly punctured. Legs long, the anterior pair moderately elongate in the ♂. Femora clavate, unidentate. Anterior tibiae bowed at the apex and mucronate at the inner apical angle. The two basal segments of the anterior tarsi of ♂ clothed with long projecting setae.

Length 4.5–8.0 mm., width 1.8–3.0 mm.

Distribution.—Cotypes, Jalapa, Mexico, Hoge Collr., Toxpam, Mexico, Salle Collr.; Cubilguitz, Chacoj, Senahu, Cerro Zunil, Las Mercedes, San Isidro, and Volcan de Atitlan, Guatemala, Champion Collr.; Volcan de Chiriqui, Panama, Champion Collr.

The elytra of the male, viewed in profile, are gibbous towards the base. A condition which also exists in some species of *Gasterocercus*, thus leading to some confusion of names in the literature.

Cophes hieroglyphica Champion

Cophes hieroglyphicus Champion 1905, p. 519.

Oblong-ovate; shining, black with the antennae and the tips of the tarsi reddish brown; variegated above with dense reddish brown, black and white scales, the black scales on the pronotum more or less condensed into two oblong spots basally, those on the elytra condensed into a curved, oblong, sharply defined streak on the disc basally, a short sutural streak behind scutellum, and various small irregular spots on the disc and near the apex, the white scales condensed into a curved line on the anterior part of the prothorax, an oblique fascia on the disc behind base, and a common, faint, interrupted, transverse, subapical fascia; the dorsum with very short, coarse, scattered setae.

Rostrum about as long as head and pronotum, moderately stout, curved, depressed basally, rugosely punctured, carinate dorsally at middle. The antennae inserted at middle. First and second segments of funicle equal in length, 3–7 transverse. Club elongate-ovate, as long as the preceding six segments united. Head densely punctured. The eyes very large, separated by about one-third width of rostrum.

Prothorax transverse, the sides strongly rounded in basal half then rapidly narrowing to the apex; feebly constricted behind apex; pronotum densely punctured. Scutellum small.

Elytra slightly wider than the prothorax, convex the sides parallel in basal third; striae serially punctured; intervals punctured and almost flat.

Ventral side sparsely clothed with brownish yellow and intermixed white scales; closely punctured. The mesosternum horse shoe-shaped. Femora feebly clavate, unidentate. Anterior tarsi of the male with a few very fine, long, projecting setae.

Length 5.1–5.7 mm., width 2.5–2.6 mm.

Distribution.—Cotypes, 4, Volcan de Chiriqui, Panama, Champion Collr.; 1, Toxpam, Mexico, Salle Collr., 1, Jalapa, Mexico, Hoge Collr.

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